THE

GEOLOGICAL MAGAZINE

VOLUME LXV.

No. III.—MARCH, 1928.

ORIGINAL ARTICLES.

Breccias.

By S. H. Reynolds, M.A., Sc.D., University of Bristol.

BRECCIAS in general have been exhaustively discussed by W. H. Norton,[1] and Bonney[2] has fully described a large number of sedimentary origin. But since these papers were written attention has been drawn to certain fresh types of brecciated rock, and perhaps a briefer account than that in Norton's paper and one referring more particularly to British examples may be of service.

A breccia may be defined as a rock composed of angular fragments united by a greater or less amount of cement, which may be similar in nature to the fragments or of a different character. The nature of the fragments may be similar or diverse.

Many rocks are intermediate between breccias and conglomerates, as they contain both angular fragments and rounded pebbles. The following classification of breccias is adopted here :—

I. Breccias of sedimentary origin.

(1) Subaerial breccias.

(*a*) Talus breccias.
(*b*) Torrent breccias.
(*c*) Cave breccias.
(*d*) Rockfall breccias.
(*e*) Glacial breccias.

(2) Subaqueous breccias.

(*a*) Talus and torrent breccias.
(*b*) Residual breccias.
(*c*) Reef breccias.
(*d*) Bone-bed breccias.
(*e*) Penecontemporaneous breccias including desiccation breccias.

[1] *Journ. of Geology* (Chicago), xxv (1917), pp. 160–94.
[2] *Q.J.G.S.*, lviii (1902), pp. 185–203.

II. Breccias of igneous origin.

(*a*) Explosion breccias.
(*b*) Flow breccias.
(*c*) Intrusion breccias.

III. Breccias due to movement.

(*a*) Fault and crush breccias.
(*b*) Fold breccias.
(*c*) Founder breccias.

IV. Breccias of chemical origin.

I. Breccias of Sedimentary Origin.

These are the most important and varied in character and extent. Many are local, others of very wide distribution. They are divisible into two groups, viz. (1) subaerial, (2) subaqueous.

(1) *Subaerial breccias.*

The agent responsible for the detachment of the fragments is commonly frost in cold and temperate regions, change of temperature in arid and tropical regions. Such breccias include :—

(*a*) *Talus breccias.*—These are cemented screes; they are of limited extent, and are composed of material of quite local origin. The term rock-glacier breccia is applied by Norton [1] to a variety of talus breccia, which is found in some mountain regions where the work of frost is specially efficient. It is characterized by its wide extension outwards from the base of the mountain, this having been attributed by Norton in part to movement due to the expansion of the interstitial ice, while a letter from Professor Garwood quoted by Bonney [2] indicates the way a talus fan may spread by the sliding of the newly fallen fragments over the snow-covered older talus slopes. The remarkable limestone breccias of Gibraltar described by Ramsay and J. Geikie [3] are grouped by Norton as rock-glacier breccia. They seem to imply much colder conditions than now obtain and to be primarily due to frost action, assisted by the " more or less sudden meltings of thick snow, such as would saturate heavy trains of debris and cause them to move *en masse* down the steep slopes and over the lower grounds beyond ".[4]

(*b*) *Torrent breccias* (bajada [5] breccias).—These are of wider extent and more variable composition than talus breccias and are characteristic of arid regions, where, partly owing to the scarcity of vegetation, the occasional torrential downpours are immensely efficient in sweeping the material down the mountain slope and distributing it over the lower ground. Here are to be grouped the

[1] Op. cit., p. 164.
[2] Op. cit., p. 201.
[3] *Q.J.G.S.*, xxxiii (1878), pp. 503–41.
[4] Ibid., p. 519.
[5] Norton, op. cit., p. 167.

Permian breccias of South Devon,[1] of the Clent and Lickey Hills,[2] of Leicestershire,[3] of South Warwickshire,[4] of the Nottingham District,[5] of the Vale of Eden,[6] of the South of Scotland,[7] and of Armagh in Ireland.[8]

The main part of the Brockram of the north of England is also clearly to be grouped as a subaerial torrent breccia. B. Smith[9] says "the Brockram represents the accumulation of a series of torrential fans swept down into the lowlands from the slopes, gullies, and chasms of a mountain range lying to the east. The angularity of the fragments points to arid climatic conditions; they are the product either of frost action or of rapid changes of temperature . . . The lowland basin held a shallow enclosed sea into which the fringing breccias were swept in nearly flat and mutually overlapping sheets".

Torrent breccias comparable with the Brockram occur in the Trias[10] of the Connecticut valley.

Probably the coarse breccia which is often met with at the base of the Torridonian in the North-west Highlands should be classed here.

(*c*) *Cave breccias* are formed in limestone caverns by the cementing together of fragments fallen from the roof. They frequently contain the bones of the animals which inhabited the cave or of their prey.

(*d*) *Rock-fall breccias.*—Landslips and rock-falls may produce deposits full of angular fragments, but these are not often united to form a compact rock to which the term breccia could be applied.

(*e*) *Glacial breccias.*—The moraines of modern glaciers are often of such a character that if consolidated they would form a breccia. Many of the deposits left by the pre-Pleistocene glaciations which have now been recognized in so many parts of the world are largely composed of angular fragments, e.g. boulder beds of Carboniferous age of the north of India,[11] and those described as Cambrian but now frequently considered to be of late Precambrian age from South

[1] B. Hobson, GEOL. MAG., N.S., Dec. V, III (1906), pp. 310–20; see also W. A. E. Ussher, *Q.J.G.S.*, xxxii (1876), p. 387, and *Mem. Geol. Survey*, "Geology of Torquay" p. 110.

[2] A. C. Ramsay, *Q.J.G.S.*, xi (1855), p. 185; E. Hull, *Mem. Geol. Survey*, "Triassic and Permian Rocks of the Midland Counties" (1869), p. 17; W. Wickham King, *Q.J.G.S.*, lv (1899), p. 97; see also Lapworth, *Proc. Geol. Assoc.*, xv (1897–8), p. 372 and pl. xii (1).

[3] H. T. Brown, *Q.J.G.S.*, xlv (1889), p. 1, and *Mem. Geol. Survey*, "Leicestershire and S. Derbyshire Coalfield" (1907), p. 56.

[4] L. Richardson and W. F. Fleet, *Proc. Geol. Assoc.*, xxxvii (1926), pp. 283–305 and pls. xii and xiii.

[5] E. Wilson, *Q.J.G.S.*, xxxii (1876), p. 533.

[6] P. F. Kendall, *Rep. Brit. Assoc., Belfast* (1902), p. 604.

[7] R. Harkness, *Q.J.G.S.*, xii (1856), pp. 254–67.

[8] E. Hull, ibid., xxix (1873), p. 402.

[9] GEOL. MAG., LXI (1924), pp. 301–2.

[10] D. P. Reynolds and P. H. Leavitt, *Amer. Journ. Sci.*, xxiii (1927), pp. 167–71.

[11] R. D. Oldham, *Geology of India*, pp. 120 and 133. Other references are given here.

Australia.[1] The breccias of the Lickey and Clent Hills were considered by Ramsay to be due to glaciers, " which flowing down some old system of valleys, reached the level of the sea and breaking off into bergs, floated away to the east and south-east and deposited their freights of mud, stones, and boulders in the neighbouring Permian seas".[2] Oldham [3] also was inclined to favour a glacial origin suggesting that they might be analogous to the Glacial-schotten of German geologists, i.e. a mixture of moraine and scree material transported and deposited by streams. As has already been stated, they are now generally classed as torrent breccias.

(2) *Subaqueous breccias.*

(*a*) *Talus and torrent breccias.*—There is no essential difference between subaerial and subaqueous talus and torrent breccias, except that the matrix of the latter may contain the remains of aquatic animals. Probably much of the Dolomitic Conglomerate or Breccia of the Bristol District,[4] of the analogous deposits of the Quantocks,[5] and of the Keuper breccias of the Midlands,[6] is a subaqueous talus or torrent breccia. The description of the Brockram [7] quoted above shows that it is also in part subaqueous. Mr. E. S. Cobbold writes that he considers the Comley breccia bed [8] to be a talus breccia.

The breccias which occur at various levels in the German Rothliegende [9] and Alpine Flysche [9] are probably analogous.

The British subaqueous breccias which have given rise to most discussion are probably those interbedded with the Upper Jurassic rocks of Sutherland. Alluded to originally by Murchison, they were subsequently described by a number of authors including Judd [10] and Blake.[11] They consist of angular blocks of Old Red Sandstone which sometimes reach a length of many yards embedded in a matrix containing Upper Jurassic fossils. Several explanations have been suggested, but it is quite clear from the latest description by Macgregor [12] that they are a subaqueous cliff-talus breccia.

[1] W. Howchin, *Q.J.G.S.*, lxiv (1908), pp. 234–59.
[2] *Q.J.G.S.*, xi (1855), p. 200.
[3] Ibid., l (1894), p. 463.
[4] See R. Etheridge, *Q.J.G.S.*, xxvi (1870), p. 174.
[5] Ibid., p. 182.
[6] C. Fox Strangways, *Mem. Geol. Survey*, " Leicestershire and S. Derbyshire Coalfields " (1907), p. 65.
[7] p. 299.
[8] *Q.J.G.S.*, lxix (1913), p. 28.
[9] See Bonney, op. cit., p. 194.
[10] *Q.J.G.S.*, xxix (1873), pp. 187–95. A section is given (p. 191) showing three bands of breccia interbedded with shale.
[11] Ibid., lviii (1902), pp. 290–310.
[12] *Trans. Geol. Soc. Glasgow*, xvi (1916), pp. 75–85. This paper, which is illustrated by four plates, gives references to all earlier British writers and summarizes their opinions. There is also a reference to these breccias in Norton's paper (op. cit., p. 171). He suggests that they may be due to landslides fallen into the sea.

(*b*) *Residual breccia* (Norton).—When an area which has been exposed to prolonged subaerial erosion, particularly if this takes place under arid conditions, is again submerged, the angular fragments spread over its surface may, perhaps after partial rounding be cemented together by the deposits of the transgressing sea and form a breccia. Much of the Dolomitic Conglomerate of the Bristol district is probably of this character, and perhaps part of the Brockram of the north of England. Norton [1] describes characteristic American examples.

(*c*) *Reef breccias.*—Masses of breccia are formed in relation to coral reefs by the cementing together of fragments broken off by the waves. Norton [2] fully describes the several varieties of coral breccia. Breccias are also characteristic of other types of reef limestone, such as those forming the reef-knolls of the Clitheroe district of Lancashire, the Craven district [3] of Yorkshire, and the Waulsortian [4] of Belgium. In some of these bryozoa are the most conspicuous reef-building organisms.

(*d*) *Bone-bed breccia.*—The bone-beds which were deposited in so many places and at so many horizons under conditions of limited sedimentation may be locally conglomerate, elsewhere breccia. This is the case, for example, with the well-known Aust Bone-bed and with that formerly exposed in the Charlton [5] railway cutting near Bristol. The Wealden [6] contains bone-beds of somewhat similar character.

(*e*) *Penecontemporaneous breccias, including desiccation breccias.*—In many limestones of shallow water origin brecciated bands occur. These are frequently *desiccation breccias* [7] and are due to the breaking up by drying of the surface of a newly consolidated band of limestone. The resulting fragments may perhaps sink for a short distance into the still unconsolidated calcareous mud beneath, or may be enclosed by the deposition of fresh limey or other material. But in either case, both fragments and matrix are of the same geological age (penecontemporaneous). Chemically and, as a rule, lithologically there is no great difference between fragments and matrix. Desiccation breccias of this type are familiar at many localities and horizons in

[1] Op. cit., pp. 162–3.

[2] Op. cit., pp. 179–81.

[3] R. H. Tiddeman, *Rep. Brit. Ass. Newcastle-on-Tyne*, 1889, pp. 602–3; also as quoted by Marr, *Q.J.G.S.*, lv (1899), p. 330; Marr fully describes the Craven breccias (pp. 343–9 and figs. 9–13) and considers them all to be tectonic.

[4] A. Vaughan, ibid., lxxi (1915), p. 12.

[5] J. W. Tutcher, *Proc. Bristol Nat. Soc.*, 4th Ser., ii (1908 issued for 1907), pp. 11–13.

[6] G. S. Sweeting, *Proc. Geol. Ass.*, xxxvi (1925), p. 416.

[7] The term desiccation conglomerate (breccia) was first used by J. E. Hyde in describing the Coal Measure Limestone of Ohio (*Amer. Journ. Sci.*, xxv, 1908, pp. 401–8). See also C. D. Walcott (*Bull. U.S. Geol. Surv.*, No. 134 (1896), p. 40); he compares certain thin-bedded brecciated limestones (shown in pl. x) with layers of fine sand and silt hardened by the sun and wind on a tidal flat, and brecciated by the incoming tide (pl. xv).

the Carboniferous Series both of Britain [1] and Belgium,[2] and are also well seen in the Purbeck beds of the Dorset coast. An excellent example is afforded by the so-called "Crazy Cotham" or "False Cotham" [3] of Sedbury and Aust Cliffs, near Bristol. Breccias of this type are alluded to by Bonney [4] as "contraction breccias" and are also sometimes called intraformational breccias. Sandstones in continental formations often enclose angular flakes of shale which doubtless arise from brecciation through desiccation. A special variety of desiccation breccia is called by Norton [5] *playa-breccia*. He describes how the cracks in the sun-baked clay of a dried-up lake bed may be filled with desert sand and how this accumulates also beneath the curled up edges of the cakes.

II. Breccias of Igneous Origin.

These include in the first place (*a*) the ordinary volcanic breccias and agglomerates produced by explosive action.[6] Such rocks commonly consist of more or less angular fragments of lava, often mingled with fragments derived from the rocks through which the volcano has broken, these being frequently of sedimentary origin.

In very many cases these breccia masses occupy volcanic vents, some of the most remarkable examples being those of the Tertiary area of Arran,[7] Skye,[8] and Mull.[9]

The peculiar limestone breccias [10] occurring in the Arenig rocks of Connemara are probably explosion breccias and are characterized by their patchy development.

Of late years the importance of (*b*) *flow-breccias* due to the breaking up through movement of the consolidated surface of a lava flow has been widely recognized, especially in the Lake District,[11] where

[1] As for example in the Avon section, Bristol; see *Q.J.G.S.*, lxxvii (1921), pp. 216, 224–6, 228–9.

[2] Brecciated limestone of this type is termed calcaire grumeleux by Professor H. de Dorlodot. The term is adopted by Vaughan, *Q.J.G.S.*, lxxi (1915), p. 26 (note). Similar brecciated limestones occur on a large scale, forming the Grande Brêche (Upper S 2) of Belgian geologists. See also J. de Lapparent, *Ann. Soc. Geol. du Nord*, t. xlvii (1922), pp. 110 and 113.

[3] A. Vaughan, *Q.J.G.S.*, lix (1903), pp. 396–8.

[4] Geol. Mag., n.s., Dec. II, Vol. X (1883), p. 438.

[5] An example of such breccias is figured in *Q.J.G.S.*, lxvi (1910), p. 557.

[6] An example from Charnwood Lodge Drive, Charnwood Forest, is included in the first issue of British Geological photographs published by the British Association.

[7] *Mem. Geol. Survey*, sheet 21, Scotland (N. Arran, S. Bute, etc.), 1903, pp. 79–83.

[8] *Mem. Geol. Survey*, "Tertiary Igneous Rocks of Skye," 1904, pp. 15–21.

[9] Ibid., "Tertiary and Post-Tertiary Geology of Mull, etc.," 1924, pp. 199–207.

[10] See C. I. Gardiner and S. H. Reynolds, *Q.J.G.S.*, lxv (1909), pp. 118–24.

[11] See J. E. Marr, *Proc. Geol. Ass.*, xvi (1900), p. 469, and J. F. N. Green, ibid., xxvi (1915), p. 202, and xxx (1919), pp. 160–6; also J. J. Hartley, ibid., xxxvi (1925), pl. xvi (1).

many such rocks were formerly thought to be tuffs. The occurrence of finely divided tuff in the spaces between the larger fragments of a breccia is not proof of the explosive origin of the rock as a whole. For, as Green [1] points out, the actual top of a flow often consists of solid andesite with clefts filled in with tuff material from above,[2] partly perhaps derived from explosions and fumeroles at the surface of the lava itself. Cracks in the crust are sometimes filled in from below with thin sheets of glass. Flow and refusion may combine to round the fragments producing flow conglomerate.

Certain of the brecciated rocks of the Bardon Hill area, Charnwood Forest, which he at first thought to be tuffs, were subsequently regarded by Bonney [3] as flow-brecciated lavas. Boulton [4] describes a fluxion tuff from Weston-super-Mare. Good examples of flow-brecciation are seen in the Precambrian pillow lavas of Ontario. Tempest Anderson describes the surface of a lava flow at Matavanu, Savaii [5] as broken up by subsequent movement, and figures a lava stream the surface of which is brecciated and forced up by a new flow making its way beneath.

It has also come to be generally recognized that, as Lapworth [6] says, " while (intrusive) igneous matter . . . may consolidate as sills where the pressure is great . . . as movement progresses intermittently we should have the formation of subterranean tuffs and breccias which would be forced locally between the bedding planes sometimes into dyke-like fissures." Many peculiar brecciated rocks from Waterford, Limerick, and other parts of Ireland are claimed by Kilroe and McEnery [7] as such " intrusive tuffs ". Watts,[8] followed by F. Jones,[9] the latest worker on Bardon Hill, considers that the rocks brecciated by movement, which Bonney, as stated above, considered to be lava, are really intrusive.

A widely different type of breccia of igneous origin is :—

(*c*) *Intrusion breccia.*[10]—Such breccias are often very well seen along the contact zone between an intrusive igneous rock and an earlier one —sometimes igneous, sometimes sedimentary—which it penetrates. Excellent examples of such rocks occur at many places in the Lizard district [11] in the Channel Islands, e.g. at Elizabeth Castle, Jersey ; also in relation to the Caledonian granitic intrusions of Galloway and

[1] *Proc. Geol. Ass.*, xxx (1919), p. 162.

[2] Mr. Green suggests (ibid., note) that such an infilling is shown by the figure on p. 92, *Q.J.G.S.*, lx (1904).

[3] Geol. Mag., n.s., Dec. VI, Vol. II (1915), pp. 545–6.

[4] *Q.J.G.S.*, lx (1904), p. 163.

[5] Ibid., xxxvi (1910), p. 628, and pl. xlviii (2).

[6] *Q.J.G.S.*, lvi (1900), p. 23.

[7] Ibid., lvii (1901), pp. 479–89.

[8] *Mem. Geol. Survey*, sheet 155 (1900), p. 8, and *Brit. Ass. Handbook, Leicester* (1907), p. 262.

[9] Geol. Mag., LXIII (1926), pp. 241–55.

[10] This term is used by Harker, *Mem. Geol. Survey*, " Small Isles," p. 69. Sederholm uses the term igneous breccia.

[11] A good example is figured by Teall, *Proc. Geol. Ass.*, xxix (1918), pl. ii (B).

the west of Scotland, in the Carlingford district of Ireland,[1] at many points along the lines of junction of the plutonic masses in Skye and Rum, and at innumerable other localities in many parts of the world.

Sometimes an intrusive rock may be so packed with cognate xenoliths as to present many of the characters of an injection breccia as in peridotites from Skye figured by Harker.[2]

III. Breccias due to Movement (endolithic breccias of Norton).[3]

The great majority of these may be grouped as *tectonic breccias*, which include :—

(*a*) *Fault and crush breccias.*—Here are to be placed the breccias often seen along the line of a powerful fault, especially if it be overthrust. Such fault-breccias grade into the large masses of crushed and shattered rock so often found in highly disturbed areas. They are typically represented by the crush-breccias passing into crush-conglomerates of the Manx slates, which have been fully described by Lamplugh.[4] The extreme disturbance and deformation shown by these rocks is associated with movement under great superincumbent pressure. The Carboniferous rocks of the same area, though also affected by the disturbances, were subjected to less pressure from overlying strata, and have been brecciated without deformation.

Equally remarkable are the great masses of crushed rock in the Mona Complex of Anglesey, described by Greenly [5] as an autoclastic mélange. They " consist essentially of lenticular strips and lumps of grit floating in a schistose matrix which sweeps curving round them ".

If the plane of the fault along which brecciation has taken place is horizontal, or nearly so, it may be very difficult to distinguish between a tectonic breccia and one of sedimentary or even of explosive origin. Thus Marr states that many of the breccias of the Borrowdale beds are fault-breccias.[6] Brecciation and violent puckering of the less rigid strata is a feature of the intraformational lag faults of the Lake District. The tear faults may also be accompanied by much brecciation.

Another remarkable breccia described by Greenly [7] is seen in connexion with the Carmel Head thrust-plane which brings Pre-

[1] Sollas, *Trans. R. Irish Acad.*, xxx (1894), pp. 478–80, and pl. xxiv, figs. 2, 3, 5.

[2] *Mem. Geol. Survey*, " Tertiary Igneous of Skye," pls. iii and iv.

[3] Op. cit., p. 185.

[4] *Mem. Geol. Survey*, " Geology of the Isle of Man," pp. 55–70.

[5] *Mem. Geol. Survey*, " Geology of Anglesey," i, pp. 65–6 (for further refs. see index), and pls. vii and xxiii.

[6] For a general account of the fault-breccias see Marr, *The Geology of the Lake District* (1916), pp. 85–8.

[7] Op. cit., p. 546, and pl. xxxii.

cambrian schists over Ordovician shales. The rock forms a mélange, the yielding shales acting as a matrix for the blocks of schist.

The Longmyndian of the Old Radnor district [1] " really represents a crush breccia on a large scale ".

Intraformational crush-brecciation along a thrust plane is well seen in the Portraine [2] section of co. Dublin. The fragments are frequently so much rounded by friction that the rock is rather a conglomerate than a breccia.

Harker describes crush brecciation in Skye as affecting all the major groups of igneous rocks, and figures [3] granite in two stages of brecciation. He also describes such brecciation in Rum.[4] A description is also given [5] of a remarkable series of vertical bands of fracture and crushing in the Torridon sandstone of northern Rum. These bands, which are only traceable for a short distance, occur in some cases associated with dykes, and seem to be analogous to normal faults, although there is no displacement. The Chalk with its included flints is much brecciated in places along the line of the great Isle of Purbeck overthrust.[6] Breccias of tectonic origin are specially common among the rocks of the south of Europe, used in Roman and later times for ornamental work. Many of them are crushed marbles, others crushed serpentinous rocks, e.g. the Verde Antique of Thessaly and a similar rock from Liguria.

Breccias in which the crushing is largely dependent on movement grade into those in which the rock is fractured, but the resulting fragments are not much displaced. Limestones are often much affected in this way, and the fragments may become separated by a network of calcite veins. Norton uses the term " mosaic breccia " [7] for a rock of this type.

(*b*) *Fold breccias.*—Thin-bedded strata, particularly shales, alternating with limestones or cherts, when sharply contorted may break up, the fragments may be displaced and rotate, and a species of breccia may result. This is well seen in the highly disturbed rocks of the coast of county Dublin, of both Ashgillian (Portraine) and Avonian (Loughshinny) age.

[1] E. J. Garwood and E. Goodyear, *Q.J.G.S.*, lxxiv (1918), p. 5.

[2] *Q.J.G.S.*, liii (1897), p. 531 (described and figured under " thrust conglomerate ").

Note.—In addition to the numerous cases alluded to in the text rocks brecciated by movement are shown in several of the plates in the *North-West Highland Memoir*. Pl. xxii is of a dyke shattered by movement but with the fragments still in contact. Pl. xxix is of phacoidal structure produced in a gneiss. Compare also J. B. Hill, " On the Crust Conglomerates of Argyllshire," *Q.J.G.S.*, lvii (1901), pp. 313–27.

[3] *Mem. Geol. Survey*, " Igneous Rocks of Skye," pl. vii, for refs. see index.

[4] *Q.J.G.S.*, lix (1903), pp. 189–201, and *Mem. Geol. Survey*, " Geology of the Small Isles," pp. 7–16 and 109–10.

[5] Ibid., pp. 61–3.

[6] *Mem. Geol. Survey*, " Geology of the Isle of Purbeck and Weymouth," pp. 214–15.

[7] Op. cit., p. 161.

(*c*) *Founder breccia* is a term used by Norton [1] for breccia produced by the collapse of strata owing to the complete or partial removal of stable rocks by the chemical action of underground water. He describes a number of American examples.

Founder breccias appear also to be represented by the Blink Klip ironstone breccia [2] of the Nama-Transvaal system (Precambrian) of South Africa. "Various stages can be studied, from the simple sagging, without breaking of the ironstone into hollows, to that in which they were fractured and then cemented by haematite and silica derived from the overlying ferruginous strata."

The most interesting British examples are the gash-breccias of Triassic age of South Wales and the breccia-gashes of the Magnesian Limestone of the north of England. The gash-breccias [3] of the Tenby district consist of a tumultuous mass of blocks of Carboniferous Limestone, and are believed to have arisen by the collapse during Triassic times of the roof and sides of solution cavities in the limestone.

The breccia-gashes [4] in the Magnesian Limestone of the Durham coast are cavities, formed by the solution of gypsum, filled through collapse of the strata above with angular debris more or less cemented by percolation into a firm breccia.

Here allusion may be made to the remarkable St. Louis breccias of the Mississippian of Iowa, though they are clearly of diverse origin. The most recent description of these rocks is by O. R. Grawe.[5] Of the various types described one (figs. 2–5) is considered to depend in the main on solution along incipient cracks in the limestone followed by collapse. It appears to be to some extent analogous to the gash-breccias of Gower. A second type (fig. 10) seems to be similar to the penecontemporaneous desiccation breccias of the British Avonian.

The curious *Broken Beds* [6] of the Isle of Purbeck are perhaps to some extent analogous to founder breccias. "Breaking" is a phenomenon which locally affects certain limestone bands in the Lower Purbeck, a greater vertical thickness of strata being "broken" in some sections than in others. No foreign material occurs, and the fact that the strata above and below the Broken Beds are quite undisturbed seems definitely to rule out any tectonic explanation.

[1] Op. cit., p. 191.

[2] A. L. du Toit, *Geology of South Africa* (1926), p. 106.

[3] E. E. L. Dixon, *Mem. Geol. Survey*, "Pembroke and Tenby," pp. 158–9, and pl. v.

[4] An excellent example is illustrated in the third series of *Geological Photographs*, published by the British Association Geological Photographs Committee. See also C. T. Trechmann, *Q.J.G.S.*, lxix (1913), pp. 189 and 217, and *Proc. Geol. Assoc.*, xxxvi (1925), p. 142. It is there suggested that possibly certain of these breccias may have had a chemical origin, being produced by "stewing in a superheated or supersaturated solution of sulphates".

[5] *Washington Univ. Studies*, xiii, Sci. Ser., No. 1, pp. 45–62 (1925).

[6] *Mem. Geol. Survey*, "Geology of the Isle of Purbeck and Weymouth," pp. 80–2.

In his description of these rocks in the Survey memoir Sir A. Strahan is inclined to follow Osmond Fisher in considering that they are contemporaneous and perhaps due to the collapse of strata following the decay of vegetable matter interbedded with them.

The curious brecciated masses of gypsum of Chellaston in Derbyshire [1] are attributed to the breaking up of nearly isolated masses of soft gypsum owing to the weight of the cap of Keuper marl.

Breccias may occur in connexion with the peculiar surface limestones formed in regions of low rainfall, such as much of South Africa, by the evaporation of ground water containing carbonates derived from the underlying rocks. The crystallization of the carbonates in the pores and cracks of the surface rocks shatters them, producing a breccia.[2]

IV. Breccias of Chemical Origin.

French and Belgian geologists describe breccias due to dolomitization.

In England we have no true breccias which have been attributed to this cause, but in the case of the pseudobreccias [3] so characteristic of the D 1 beds of the English and Welsh Carboniferous Limestone, we are dealing with a rock-type in which the appearance of brecciation is brought about by a process of recrystallization, by which the argillaceous and ferruginous material has become concentrated in the "matrix", leaving the "fragments" relatively free from impurities. Another case of brecciation due to chemical action is afforded by the hydration of anhydrite. When anhydrite takes up water and becomes gypsum, the space it requires is increased by more than a quarter, and the rock may be shattered, the gypsum forcing its way along the planes of fracture much as if it were an intrusive magma.[4]

In other cases the appearance of brecciation in a limestone may be produced by the occurrence of angular areas showing conspicuous staining, from which the remainder of the rock is free.

[1] B. Smith, *Q.J.G.S.*, lxxiv (1918), p. 180.

[2] A. L. du Toit, *Geology of South Africa* (1926), pp. 357–8.

[3] *Mem. Geol. Survey*, "Geology of Swansea," p. 10, and E. E. L. Dixon and A. Vaughan, *Q.J.G.S.*, vol. lxvii (1911), pp. 507–11. See also *Rep. Brit. Assoc. Oxford* (1926), pp. 89–92.

[4] J. W. Evans, *Proc. Geol. Assoc.*, xxv (1914), p. 229.

On Hill-slopes.

By Philip Lake, M.A., F.G.S.

SOME time before the war I examined the profiles, or longitudinal sections, of several rivers, with the object of ascertaining whether they tended towards any particular curve. The method of examination was similar to that employed by Professor O. T. Jones in his interesting paper [1] on " The Upper Towy Drainage System ", but the data were obtained from maps and were not so exact as his. Some rivers showed a very close approximation to a catenary for the greater part of their course, but this was not the case with all. My final conclusion was that there is no general curve towards which all river-profiles tend : the form is influenced by the rate at which the volume of the river increases downwards. No sufficient data, however, were available in the case of any river for the exact application of a general theory which was in my mind, and such approximations as were possible were too rough to be of any real value.

A river with its tributaries is a very complex system, and it seemed that a smooth unchannelled hill-slope offers a much simpler problem. There is no lateral concentration of the flow, and it cannot be far from the truth to assume that the water to which they owe their form flowed as a sheet. Moreover, in many hill-slopes the gradient is very steep towards the top and diminishes rapidly towards the foot. Comparatively rough observations will determine the character of the curve with as great certainty as more precise observations where the gradient changes slowly.

Accordingly I measured a number of short and steep grass-covered hill-slopes between Bethesda and Aber, in Carnarvonshire. My first intention was to choose portions of slopes limited above and below by outcrops of harder rock. Owing to their much greater powers of resistance these outcrops might be considered as affording relatively fixed points in the profile. But the district did not offer many good examples of this kind.

No assistance being available, the observations were made by myself with hand instruments. A base of suitable length was measured at the foot of the slope at right angles to the plane of the section required and its ends were marked. Proceeding up the slope distances from this base were measured with an Owen topometer, an instrument which in principle is a sextant with about the accuracy of the ordinary box sextant, i.e. capable of measuring to a minute of angle. As used in these observations, it determines the distance by measuring the angle subtended by the base, and from previous experience and many tests I should judge that even the longer distances are correct within about one per cent. At each point where the distance was taken the angle down to the base was observed

[1] *Quart. Journ. Geol. Soc.*, vol. lxxx (1924), pp. 568–607.

with an Abney level, reading to 10′ and by estimation to about 3′ and frequently tested. From these data the horizontal distance to the base and the vertical height above it were found.

For very short and steep slopes another method was employed. By means of a hand level used at a height of 5 feet above the ground, a series of points in the line of section was determined at 5 feet, 10 feet, and so on above the base. The distance of each from the base was measured with the Owen topometer, and since the vertical height was known the horizontal distance was found without any measurement of angle. There can hardly be an error of more than a few inches in the heights or of more than two or three feet in the horizontal distances. The profiles which were measured in this way are easily distinguished by the fact that the heights are all multiples of five.

In measuring the actual distances the observations were taken to the nearest unit. In converting them into horizontal distances and vertical heights the figures have been carried to the first decimal place.

Nine profiles were measured at different times, and the whole series of observations is given below, although in some cases the number of points fixed is too small to be of much value. In the following tables the point where the base crosses the plane of the section is taken as the origin of co-ordinates. The column headed "x" gives the horizontal distances from this point, and the column headed "y (observed)" the vertical heights above it. In the first two profiles, which are much the longest, the unit is a yard, in the others it is a foot.

All the profiles are very nearly arcs of circles. The differences are, indeed, so small that they are better shown numerically than by diagrams. A circle can be drawn through any three points, and in each profile three points have been selected and a circle is imagined to pass through these points. For each of the observed values of x the height of this circle above the base has been calculated, and is entered in the column headed "y (circle)", so that direct comparison with the observed profile is easy. To distinguish these selected points, at which the values of y for both circle and profile are necessarily identical, square brackets are used. The figures have been independently checked by a friend, but to save the reader some labour if he should wish to check any of them himself, the co-ordinates, a and b, of the centre of the circle, and its radius r are given at the foot of the column. In most cases it has been sufficient to carry these to the first place of decimals, but sometimes the second place is necessary in order to obtain y correct to the first place.

For reasons which will appear subsequently the values of y for a parabola with its axis horizontal, passing through the same three selected points, are shown in the fourth column. At the foot of this column are given the co-ordinates a and b of the vertex of the parabola, and also the constant k on which its form depends.

DETAILS OF THE PROFILES.

I. North-west face of Moel Wnion. Covered with grass and other low vegetation. At the top the profile merges into the upper convex part of the hill, at the foot it is cut off abruptly. Measurements in yards.

x	y (*observed*)	y (*circle*)	y (*parabola*)
83·8	19·3	[19·3]	[19·3]
111·8	26·8	26·7	26·9
130·0	32·4	31·9	32·1
157·0	40·1	[40·1]	[40·1]
228·6	66·3	65·6	64·1
320·8	106·3	[106·3]	[106·3]
		$a = -202{\cdot}6$	$a = 379{\cdot}3$
		$b = 1166{\cdot}2$	$b = 176{\cdot}05$
		$r = 1182{\cdot}1$	$k = -83{\cdot}15$

II. North-west face of Moel Wnion, parallel to and about 30 yards east of Profile I. Measurements in yards.

x	y (*observed*)	y (*circle*)	y (*parabola*)
74·8	18·2	[18·2]	[18·2]
123·2	30·7	30·5	31·0
166·4	43·6	[43·6]	[43·6]
213·5	60·8	60·2	59·4
276·8	86·5	[86·5]	[86·5]
		$a = -161{\cdot}1$	$a = 338{\cdot}2$
		$b = 1048{\cdot}3$	$b = 150{\cdot}26$
		$r = 1056{\cdot}76$	$k = -66{\cdot}2$

III. Braich Melyn (on the east side of Nant Ffrancon near Bethesda). A short grass-covered slope, limited at the top by an outcrop of hard rock, merging below into a nearly level flat. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
32·9	5·0	[5·0]	[5·0]
56·1	10·0	9·2	9·7
79·6	15·0	[15·0]	[15·0]
97·0	20·0	20·3	19·6
144·6	40·0	[40·0]	[40·0]
		$a = -22{\cdot}3$	$a = 149{\cdot}9$
		$b = 376{\cdot}8$	$b = 49{\cdot}5$
		$r = 375{\cdot}9$	$k = -16{\cdot}9$

IV. Braich Melyn. The north side of a small dry valley, grass-covered, limited at the top by an outcrop of hard rock, merging below into the floor of the valley. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
39·6	5·0	[5·0]	[5·0]
47·6	10·0	[10·0]	[10·0]
55·0	15·0	15·3	15·2
61·0	20·0	[20·0]	[20·0]
		$a = -42{\cdot}3$	$a = 80{\cdot}6$
		$b = 144{\cdot}6$	$b = 53{\cdot}65$
		$r = 161{\cdot}85$	$k = -57{\cdot}7$

V. Braich Melyn. The south side of the same little valley. Grass-covered, limited above by an outcrop of rock, merging below into the floor of the valley. The base was the same as for Profile IV, and the two profiles accordingly combine to form a section across the valley. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
36·3	5·0	[5·0]	[5·0]
50·0	10·0	9·6	9·9
62·4	15·0	[15·0]	[15·0]
72·3	20·0	20·2	20·0
80·2	25·0	[25·0]	[25·0]
		$a = -9·2$	$a = 91·4$
		$b = 163·0$	$b = 41·45$
		$r = 164·4$	$k = -24·1$

VI. Braich Melyn. Grass-covered, rock cropping out above but not forming a very clearly defined limit, merging below into a flat. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
29·1	2·4	[2·4]	[2·4]
49·2	5·9	5·7	6·2
67·7	10·3	[10·3]	[10·3]
85·9	16·4	16·2	15·2
102·4	23·0	23·0	21·2
113·2	28·2	[28·2]	[28·2]
		$a = -2·6$	$a = 115·5$
		$b = 255·9$	$b = 33·24$
		$r = 255·47$	$k = -11·0$

VII. Braich Melyn. The same slope as VI, but not the same line. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
40·0	4·4	[4·4]	[4·4]
62·4	8·9	9·8	9·9
83·1	15·9	[15·9]	[15·9]
101·4	22·2	[22·2]	[22·2]
		$a = -54·8$	$a = 137·2$
		$b = 446·2$	$b = 49·67$
		$r = 451·9$	$k = -21·1$

VIII. Braich Melyn. Grass-covered, rather badly defined above by outcrops of rock, merging below into a small flat. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
34·9	2·6	[2·6]	[2·6]
61·7	6·5	8·4	9·8
76·9	12·9	13·4	14·5
92·9	20·0	[20·0]	[20·0]
106·4	27·9	26·9	25·5
127·1	39·3	40·0	36·8
138·2	48·5	[48·5]	[48·5]
		$a = 3·4$	$a = 139·9$
		$b = 212·8$	$b = 55·17$
		$r = 212·55$	$k = -26·32$

IX. Braich Melyn. A part of the same slope as VIII, special care being taken to choose a line free from irregularities. Measurements in feet.

x	y (*observed*)	y (*circle*)	y (*parabola*)
33·4	3·6	[3·6]	[3·6]
41·5	6·7	6·8	6·9
44·7	8·3	8·1	8·2
52·6	11·8	[11·8]	[11·8]
60·8	16·7	16·0	15·9
69·0	20·9	20·8	20·7
73·9	23·9	[23·9]	[23·9]
		$a = -36·3$	$a = 91·4$
		$b = 193·4$	$b = 48·65$
		$r = 202·2$	$k = -35·0$

Throughout the whole series there is only one instance in which the value of y for the circle differs by more than a unit from the corresponding observed value. This is in profile VIII, in which, for $x = 61·7$, y for the circle is 8·4, while the observed value is 6·5. In the same section at $x = 106·4$ there is a difference of a unit. Elsewhere, throughout the series the difference is always less than a unit. This was one of my earliest sections, and when I found that it seemed to be exceptional I took an opportunity, a year or two later, of re-examining the ground. It then appeared that farther along the slope hard bands of igneous rock crop out. Traced towards the line of the section these bands disappear beneath the soil, but their influence upon the form of the surface remains perceptible for some distance, perhaps to the line of my section, which I could not now identify precisely. Profile IX was taken on the same slope, but on this occasion I took care to choose a line beyond the influence of these irregularities.

Allowing for the comparatively rough method of measurement and also for the roughnesses incidental to a covering of mountain grass and vegetation, the closeness of the approximation to a circular arc in so many profiles can hardly be due to accident, and suggests that there must be some cause tending to produce this form.

Many years ago A. Tylor suggested that the profile of rivers tends to a parabolic curve, and in one of the figures [1] accompanying his paper " On Quaternary Gravels " he draws attention to the parabolic form of the slope represented. His views on this subject did not meet with the approval of the Geological Society and several of his papers were published in abstract only. The most complete exposition of his ideas with which I am acquainted is to be found in the report of a lecture given by him and published in the Geological Magazine for 1875 (pp. 433 to 476, with many figures). His reasoning is far from clear, but his general principle appears to be that running water will tend to produce such a slope that its velocity will be uniform throughout.

In recent years Dr. H. Jeffreys [2] has investigated the form of an

[1] *Quart. Journ. Geol. Soc.*, vol. xxv (1869), p. 73.
[2] *Phil. Mag.*, vol. xxxvi (1918), pp. 179–90.

ideal peneplain that would sink at a uniform rate all over owing to the denudation caused by the flow of surface water during rain under ordinary English conditions. It is assumed that the resistance to the motion of the water will be due mostly to viscosity and that turbulence is unimportant. Under these conditions he finds that the form will be practically parabolic, with the axis of the parabola horizontal. Corrugations along the slope will tend to disappear, so that for such irregularities the form is stable, but corrugations down the slope will become accentuated unless there is some stabilizing cause. He is inclined to look upon grass and other vegetation with fibrous roots as an important stabilizing influence.

The slopes which I have examined were not, I think, formed under the conditions which Dr. Jeffreys investigated, but it is of interest to see how nearly they approach the parabolic form.

It will be seen that in profiles III, IV, V, VII, and IX the parabola fits the observed values about as well as the circle. All of these except III are too short to give much difference between the values of y for the parabola and for the circle. Profile III is long enough, and with sufficient variation in the value of y to bring out the difference between a circle and a parabola, but unfortunately in this profile, which was the first measured, there is a considerable gap without observations between $x = 97{\cdot}0$ and $x = 144{\cdot}6$, and it is here that the circle and parabola would diverge most widely from each other.

In the remaining profiles the differences between the parabola and the circle in the lower part are not usually great, but between the middle and the upper selected points all the values of y for the parabola differ from the observed values by more than a unit (1·4 is the smallest difference), while for the circle it is only in profile VIII that there is ever a difference of as much as a unit. In these longer profiles, in fact, the circle fits much better than the parabola.

Age of the Slopes.

The slopes which have been examined are not cut in solid rock. They are evidently formed of the fragmental material washed down the hill-sides, most of it fairly fine. The figures which have been given are sufficient to suggest, if not to prove, that the conditions under which they were formed tended to produce a circular arc.

I leave the theoretical discussion of this form for a future occasion; but, apart from theory and independently of the nature of the curve, whether it really tends to the circular form or not, the Moel Wnion profiles bring out a very interesting point. They are hardly upon the flanks of the elliptical dome-like mass which forms Moel Wnion proper, but belong rather to a spur which continues its longer axis towards the north-east. The top of the spur, which is here some four or five hundred feet below the top of Moel Wnion, is broad and plateau-like, but the cross-section is rounded like the top of Moel

Wnion itself. The profiles were taken upon the seaward face of this spur, their upper extremities being placed where the convexity of the top passes into the concavity of the flank. There is a continuous, though not uniform, slope down to the sea, without any intervening obstructions. (Fig. 1.)

In all the other profiles the slope passes so imperceptibly into the flat at its foot that it is impossible to say precisely where the slope begins. But the Moel Wnion profiles are cut off abruptly at their lower ends. The curve terminates in a terrace built out upon the side of the hill. The terrace is formed largely of pebbles, many of which are well rounded, but there is finer material also mixed with the pebbles. Its upper surface slopes gently outwards, but its outer

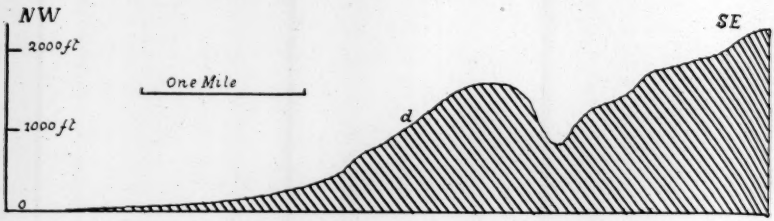


FIG. 1.—Section through the Moel Wnion spur, showing the approximate position, *d*, of the delta upon its seaward face. Vertical scale about 2½ times the horizontal scale.

edge is steep. Laterally it does not extend for more than a few hundred yards and towards the sides it becomes rather ill-defined. Such a terrace, evidently of water-borne material, could not be built upon a steep hillside unless water stood at that level when it was deposited, and it is clearly a delta. (Fig. 2.)

The terrace stands between 1,100 and 1,150 feet above the sea, and there are other similar accumulations of pebbles at this height elsewhere in the neighbourhood. No evidence of marine origin is visible, but it seems clear that these deposits were formed during the Glacial Period, for numbers of boulders are strewn along the seaward flank of Moel Wnion at this level and for some distance downwards. It seems probable that the water in which the delta was deposited was dammed against the side of the hill by the ice of the Irish Sea; but the only point with which we are here concerned is that the terrace in which profiles I and II end was formed in water standing at a height of rather more than 1,100 feet on the seaward slope of the Moel Wnion spur, and that the deposition took place during the Glacial Period.

In both profiles the lowest point shown in the tables is on the surface of the delta, near its outer edge, and it is clear that both were graded to the old water-level. The grading is still perfect, and the conclusion seems to be inevitable that the slope as it now exists was formed during the Glacial Period.

At first it may appear improbable that a slope formed during the Glacial Period should remain so long unaltered ; but there are several considerations which should be borne in mind. At the present time, even in the heaviest rain, we do not see water running down these slopes except in any channels that may exist in them. On the slopes themselves the water is caught in the grass or soaks into the soil, and it is only at the foot or on the banks of the channels that it oozes out and sometimes trickles slowly through the grass. From what one actually sees on such occasions, one would expect denudation in the channels, but the grass covering of the slopes appears to be a very efficient protection.

Even in the rare and phenomenal rains known as " cloud bursts ", the visible erosion is usually confined to pre-existing channels. Occasionally a new channel may be cut in a grassy slope, and here the erosion is great, but the rest of the slope shows no apparent sign of change.

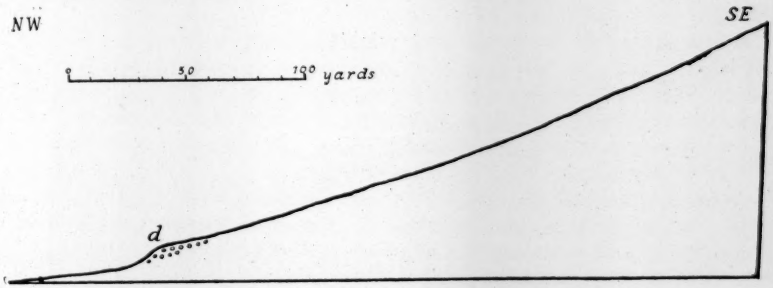


FIG. 2.—Profile I. The graded curve terminates below in the delta *d*. The section is continued to the point from which the measurements were made Vertical and horizontal scales the same.

On Moel Wnion the facts seem to suggest that since the ice receded perceptible erosion has been confined to the channels. The profiles are in conformity with the old water-level indicated by the gravel terrace. But some twenty or thirty yards west of profile I a small stream runs down the hill and crosses the terrace. It is not forming or adding to that terrace. On the contrary, it has cut a deep steep-sided channel through it, and in its own profile there is little, if any, sign of the terrace left.

Towards the close of the Glacial Period during spring and summer there must have been much greater floods of water produced by the melting of the ice than we experience now. In Greenland and Iceland during the summer water is liberated all along the edge of the ice, and there is accordingly, a much nearer approximation to the flowing of water as a sheet than we ever see.

It seems likely that the Moel Wnion slope was produced by such floods and was adapted to the volume of water which was then in

action. The relatively small amount of water which has been since available could produce no noticeable change, especially after the growth of a covering of vegetation.

It was, however, at an early stage of the melting period that the slope was produced, for water stood on the seaward face to a height of 1,100 feet, and the ice of the Irish Sea must have stood at least as high. The Welsh ice then rose above the Moel Wnion spur, and its melting in the summer could not fail to send water down this slope. At a later stage the surface of the Welsh ice sank below this spur, and since then there has been nothing but the rain falling upon the slope itself or on the plateau above to supply the water running down it.

In view of the relative permanence here ascribed to the Moel Wnion slope, apart from the channels cut in it, it is interesting to consider the bearing upon this question of the observations recorded by Darwin in his book on *The Formation of Vegetable Mould, through the Action of Worms*. The average inclination of the surfaces on which his observations were made was 9° 26′, and he finds that on such a slope the average downward displacement of the material brought up in worm-casts is about an inch in a year. From other observations as to the amount of material present in this form he estimates that on such slopes 2·4 cubic inches of earth will cross each yard of contour line in a year.[1]

It is easy to calculate the effect of this action upon a slope such as profile I. For rough calculations we may take the length of the profile, measured along the surface, as 300 yards, though actually it is nearer 350. If we imagine a strip a yard wide along the line of the profile 2·4 cubic inches of earth derived from this strip are discharged at its lower end in each year, and removed from the strip altogether. The area of the strip is 300 square yards, or 388,800 square inches. If the rate remains constant and the loss of material is distributed evenly throughout the strip it would mean a lowering of the surface by 1 inch in 162,000 years.

Actually the inclination of the upper part of the profile is much greater than 9° 26′, and that of the lower part much less; probably the loss would not be evenly distributed, and there would be some gain from the convex portion of the hill above. On the whole, there seems to be no serious inconsistency between Darwin's figures and the practically unchanged form of this profile since the Glacial Period.

Moreover, Darwin's estimates are based upon the spreading of worm-casts. A worm-cast is a heap raised above the general level of the surface on which it rests. The observations give an idea of the rate at which such irregularities on a graded surface are reduced to grade, they are in no way a guide to the rate of denudation of the graded surface itself.

It should be added that in the case of the remaining profiles there is no such clear evidence as to the age of the slopes.

[1] p. 269 (edn. 1881).

The Origin of the Dwyka Conglomerate of South Africa and other "Glacial" Deposits.

By C. G. S. Sandberg, Dr. è. Sc.

(PLATE IV.)

TO reopen a question which has seemed definitely settled ever since 1898, and which has accordingly become an accepted opinion in geological circles, is neither a pleasant nor an enviable task. Yet, as the question is one of universal interest geologically, it has to be tackled and settled. In the following I intend to discuss the problem in a manner as objective and concise as possible, in order to concentrate the argument on the points which fundamentally govern the problem. As, from personal observations on the spot I am only familiar with the South African occurrence, I intend discussing that one only, however likely it be that the arguments brought forward may fundamentally affect the appreciation of other similar occurrences in South America and Asia.

From the middle of the nineteenth century (1)[1] the question of the origin of the Dwyka conglomerate (or "tillite")[2] was controversial (3, 12, 6) until Molengraaff in 1898 decided in favour of the glacial theory (12, 13). Apart from other objections, the nature of which we will discuss below, the acceptance of the current view on the origin of the Dwyka seems very difficult indeed because of the obvious impossibility of propounding a plausible cause and mode of evolution of such a glacial period in a region which, not only is now sub-tropical (between 22° S. and 34° S.), but must have been under similar climatic conditions at least during the interval between two parts—if not during the whole—of the period of assumed glaciation.

The last sceptical opinion[3] expressed on the subject was, so far as I have been able to discover, that of D. Draper in his paper on "The Dwyka Conglomerate" (3), in which he describes its characteristics in general and in particular as he observed them in the Vryheid and Zululand districts. He concludes by raising the question of its volcanic or non-volcanic origin. The deposit is so well known geographically and geologically that it may suffice to recall its most salient features: It constitutes the basal part of the Karroo system, and extends, so far as it is known on the African continent, over the area between 22° S. and 34° S. (see map, Fig. 1), with its principal development round about the Basutoland region; "serie comprehensive" (P. Termier) of the fully developed system,

[1] Figures in parentheses refer to List of Authors quoted at end of paper.

[2] The use of the term "conglomerate" to describe the boulder-bearing rock is, it should be pointed out, not a satisfactory one, for the reason that the inclusions are rarely abundant enough to bring the rock within the usual definition of a conglomerate . . . wherefore the name "tillite" was suggested. . . . (22), p. 205.

[3] G. S. Corstorphine's exposition of the question (*S. Afr. Ass. for the Ad. of Sc.*, 1904) was not inspired by scepticism regarding the correctness of current conviction which attributed a glacial origin to the Dwyka conglomerate.

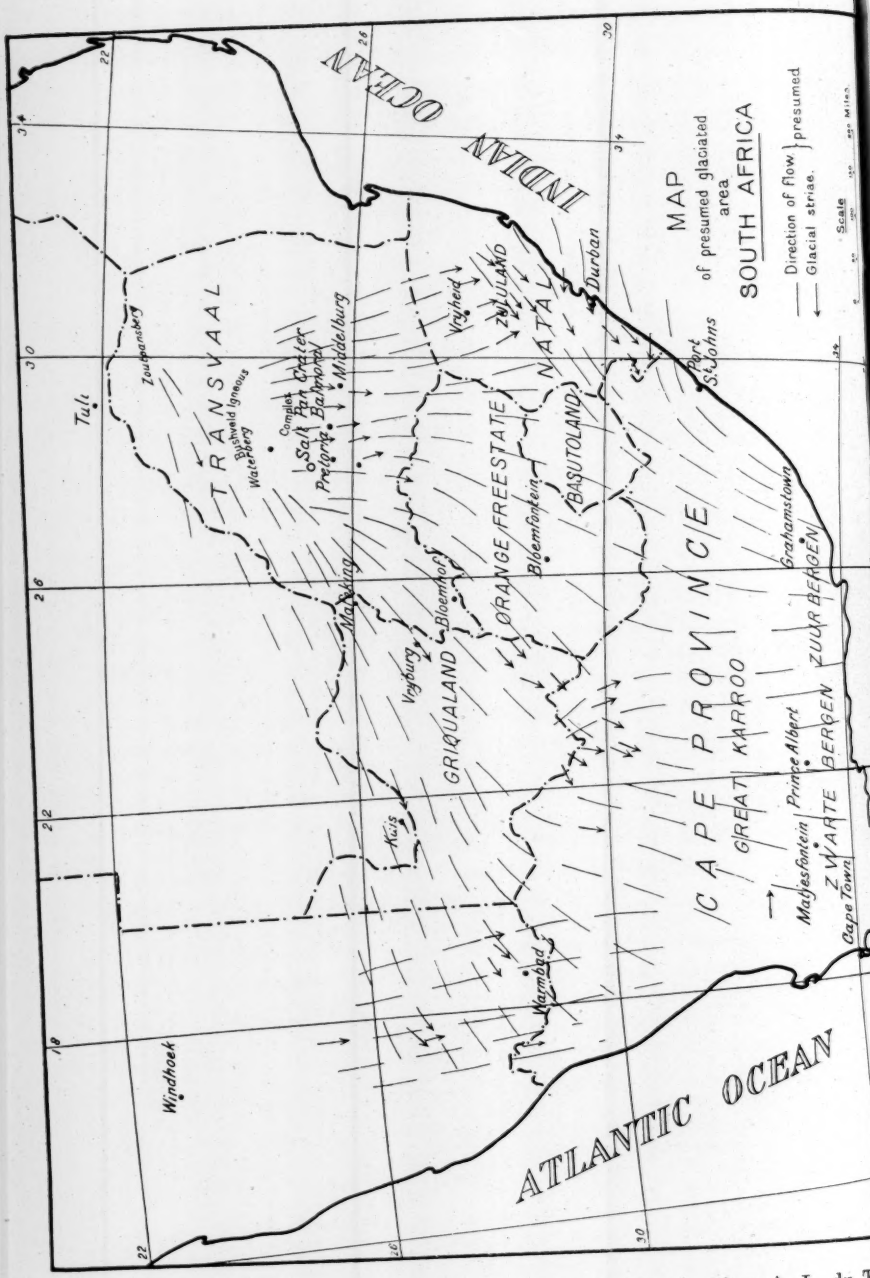


FIG. 1.—Sketch-map of the Dwyka covered area of South Africa. After A. L. du Toi

from its base to its top and even beyond to the top of the Stormberg Series ; as a whole unfolded, on the whole horizontal, locally following the undulations of its substratum ; lying unconformably on various older formations ; the so-called " conglomerate " generally at or near the base of the series ; sometimes containing scratched pebbles and boulders of various size, semi-angular, sometimes flat and polished, always imbedded in a crystalline matrix of small angular or semi-angular fragments of various rocks and minerals bearing a pronounced local character and with a preponderance of igneous material, quartz, and felspar ; substratum of older rock, sometimes striated and grooved by parallel straight striae. Modes of deposition : in banks, unstratified, and also stratified.

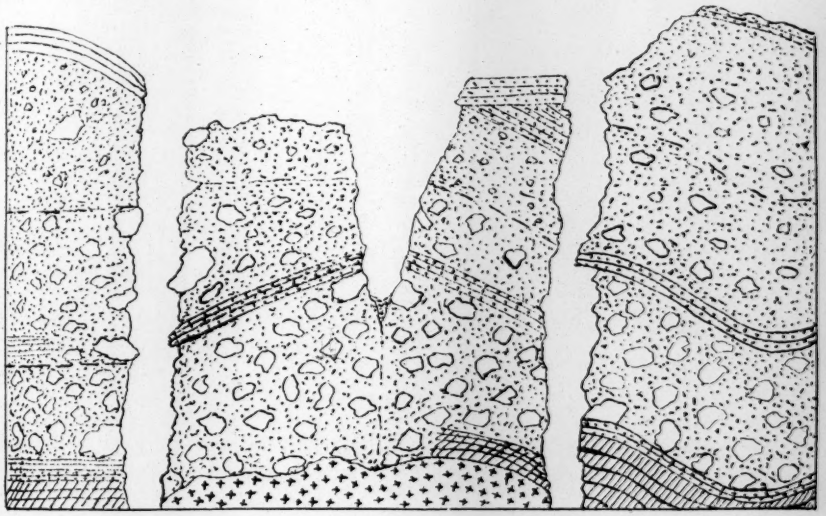


FIG. 2.—Ideal section of Dwyka deposit, after personal observation and descriptions of various authors, showing its characteristic structural features, e.g. its mode of deposition in banks and locally its alternation of stratified and unstratified portions.

A. G. Bain (1) called it a " claystone porphyry " and considered it to be " the production of an immense volcano " situated somewhere in the central part of the Dwyka-Ecca covered area. He mentions in support of his volcanic theory that sections of it, hundreds of feet in height, at Pluto's Vale in Albany, Toverberg (Western Karroo) and elsewhere are devoid of any stratification. Similar conditions have been observed by Molengraaff (12) in Vryheid. Yet, whereas Bain quotes these instances in support of his volcanic theory, Molengraaff takes such conditions to be typical of " ground moraines *stricto sensu* " (12, p. 70). Similar contradictory arguments are

found in Molengraaff and Draper. "Alternating stratified and unstratified deposits occur in the Dwyka conglomerate" (12, p. 70), as in all glacial deposits, declares the former, whilst the latter emphasized that the stratified condition of the Dwyka-Ecca, very often well developed or marked by rough planes of stratification, and its general mode of occurrence in thick more or less horizontal banks are irreconcilable with the assumption of a glacial origin of the deposit in question (3, pp. 99 et seq.).[1] As to Draper's description of its mode of occurrence, there is no difference of opinion; it is the conclusions based on the established conditions which differ. In fact, Molengraaff says (13, p. 106): "The unstratified part presents a rough division in big horizontal banks, each of which is completely

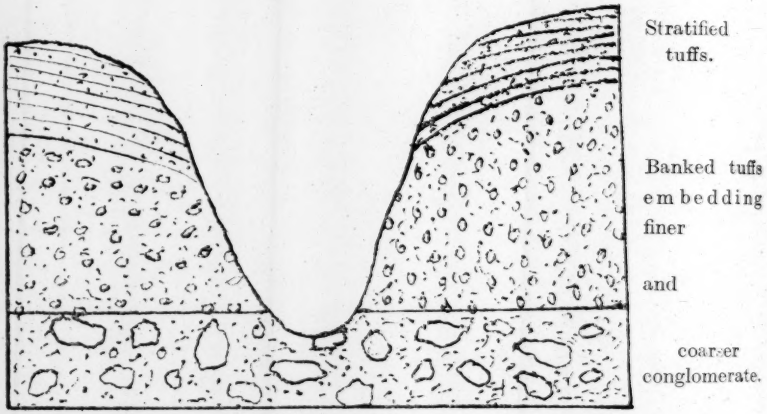


FIG. 3.—Section of the Pring torrent (Java) after N. J. M. Taverne (20, p. 8) showing banked condition of unstratified portion, accumulation of greater boulders and blocks in the basal parts and topping by stratified tuffs of products of contemporaneous volcanism.

unstratified. In the unstratified banks only sub-angular or edge-rounded boulders are found. In the stratified beds both sub-angular and more or less rounded, water-worn boulders and pebbles are met with."

It is clear that Draper's objection is not in the least weakened by Molengraaff's statement that alternation of stratified and unstratified deposits is a common feature of glacial deposits, such arrangement

[1] It should be distinctly understood that the individualization of the Dwyka and the Ecca Series—as it seems agreed upon by the Geological Survey of the Union of S. Africa—and their subdivisions, is purely artificial and conventional even for the Cape Province occurrence. Stratigraphically and palaeontologically they are identical and even petrologically they are but variations in size and local enrichments of one fundamental substance, *which is of igneous origin*, the various expressions of which are not even restricted to definite horizons.

not being exclusively found in glacial deposits. It equally *and more generally* pertains to deposits of volcanic origin. Moreover, in glacial deposits the occurrence of such stratified parts should be restricted to the margins of the glaciated area, as Molengraaff rightly remarks (12, p. 71), evidently without realizing that field evidence utterly contradicts this essential, *which is the more stringent since his and current conceptions require that at least the vast area of South Africa mentioned above should have been covered by an ice-cap of some thousand metres in thickness.* Fully realizing the contradiction between the ice-cap theory and field evidence, embodied in the occurrence of these

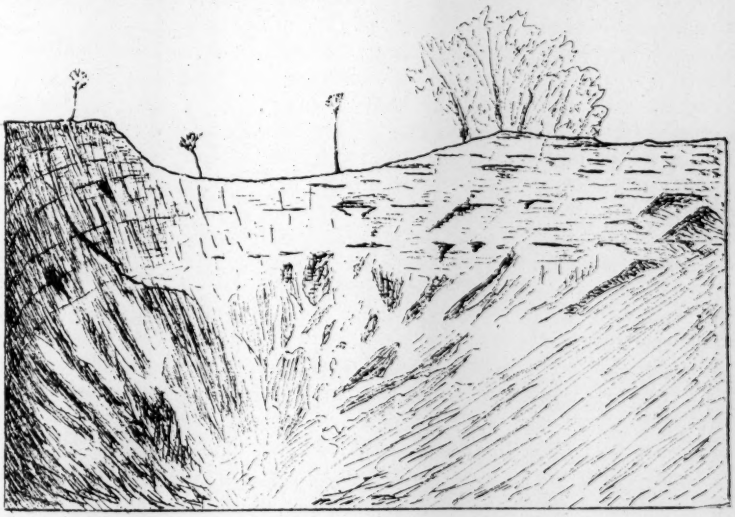


FIG. 4.—Source of Pring torrent (Java) showing conditions as depicted in section, Fig. 3. Copied from a photo by N. J. M. Taverne (20, p. 8).

stratified Dwyka deposits, brings E. J. Dunn to the conclusion that the conglomerate must have been the product of debris carried along by drifting icebergs pushed ashore by wind or ocean currents. Molengraaff, however, rightly objects that such a conception can never explain the polished and striated surfaces, often showing one or more *systems of parallel, straight striae*,[1] on the substratum of the

[1] Small straws show the direction from where the wind blows. du Toit also records instances of the conglomerate's substratum showing two or more systems of parallel, straight striae forming angles mutually. He concludes that they must have been caused by ice-bodies having flowed successively in the directions indicated by these striae. Now considering the magnitude of the assumed ice-cap, such changes in the course of the flows seem very improbable indeed. Besides, the chances are, should such variations have occurred, that the intense eroding and polishing power of these huge ice-flows would have effaced completely any mark produced by a preceding flow on their common substratum. The very existence of these systems would seem to point towards an origin different from the one assumed and actually current.

conglomerate as actually observed in various parts of the area (3, 6, 10, 12, 22). A. L. du Toit (22), accepting the view now generally adopted in geological circles, that of the ice-cap, stratigraphical and structural conditions of the deposit observed in various parts of South Africa, obliged him to assume an intricate system of vertical movements, to which various parts of the glaciated area would have been subjected during the period of glaciation. In his summary, sub. 7 and 8 (22, pp. 226–7), du Toit concludes :—

" 7. With the retreat of the ice the sea invaded the till-covered region of the north-west and by its further encroachment led to the development of a great estuary covering practically the whole of the Cape Province (south-west of the line Mariental–Kuis on the Molopo–Vryburg–Port St. John : it connected with the ocean on the west and was presumably bounded by land on the south—' certainly on the north and east ' ; (22, p. 215) along the north-eastern side of which ice-rafting occurred. . . . Deep water followed up the retreating ice-tongues and green and black muds were laid down upon the glacial deposits. . . . Accumulation of this carbonaceous horizon must have occurred " (over 180,000 square miles) " in a land-locked basin. . . . Undoubted marine mollusca have not yet been discovered in the Union."

" 8. In the north-east either the land rose owing to isostatic readjustment as the ice-cap melted " (to the south it subsided under such conditions) " or else the country lay too high to be submerged immediately. . . . Nevertheless, ultimately the greater part of this region experienced subsidence and became covered by deltaic deposits—the Transvaal coal measures—and by still higher zones of the Karroo System." (The bracketed remarks are mine.)

It should be noted now that when tracing this dividing line on the map we find it to go right through the middle of the region of maximum development of the Karroo System, where this line crosses the Basutoland region. Yet no corresponding faulting or other dislocation of the series, its cover or substrata is known along the line above mentioned ; on the contrary, the comprehensiveness, the continuity of the series and its covering in lateral and vertical sense is, tectonically, comparatively undisturbed. Neither can the assumption of a balancing see-saw movement, with the Mariental–Kuis–Vryburg–St. Johns line as its horizontal axis, explain a facial dissimilarity of the deposits north and south of this line, the existence of which du Toit's detailed study would seem to have disclosed. Last, though not least, it seems hardly reasonable to assume a negative isostatic readjustment movement (rising of the land) as a result of the melting of the ice-cap to the north of the said line when this very melting to the south of it is supposed to have been followed by a positive movement (a subsidence of the land). Apart from being hopelessly confusing and mutually irreconcilable, these assumptions do not explain the occurrence of the *alternation* of *stratified* and *unstratified* parts in the Dwyka deposit which Molengraaff attempts

to account for by laying it down that (12, p. 71): "The periodical forward and backward movement of the ice suffices of itself to produce in every instance *alternations* of *stratified* and *unstratified* glacial deposits *in the outer zones of the glaciated area*" (my italics).

A little further Molengraaff emphasizes:—

"It is evident that towards the centre of a huge area of glaciation (ice-cap or continental glaciation) the glacial deposits will be poor in, or entirely devoid of, stratified portions, whereas towards the outskirts the stratified deposits will increase in area and bulk, so that in many places they may predominate over the unstratified true boulder-clay." (The thickness of the ice-cap is "not extravagantly" estimated by du Toit (22, p. 209) at 4,000 to 5,000 feet !)

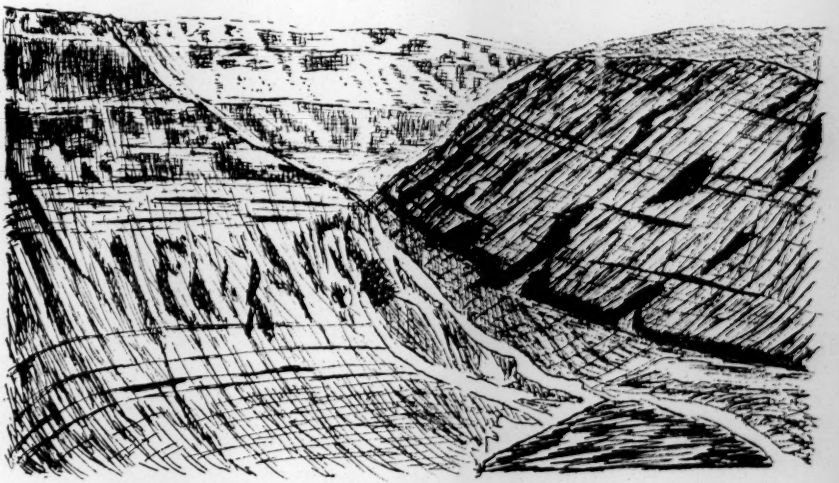


FIG. 5.—Horizontally stratified tuffs of the Batoer Volcano, Isle of Bali, Netherlands E. Indies, on primary site. Similar well defined strata, showing marked undulations have also been observed by me in this region. After G. L. L. Kemmerling. De aardbeving van Bali op 21 Januari, 1917 (Foto No. 5), *Jaarbock v. h. Mijnw. Verh.* 1e D., 1918, Batavia.

It cannot be denied that Molengraaff's conclusions, however based on a contentious presumption, are logical and unassailable—and more so even under the presumed conditions of the alleged glaciation. It would seem, however, that the obvious fact has been overlooked as yet, that these conclusions thoroughly invalidate any attempt at explaining the embarrassing existence of these stratified parts.

First, a *rudimentary* stratification, the banked habitus, far from being restricted to the outskirts is a *characteristic of the entire deposit*; secondly, a glance at du Toit's map (Fig. 1.) clearly reveals the fact that the occurrences of well developed stratification, as established

in Vryheid (Molengraaff), Zululand (Draper), Elands River, near Balmoral (Mellor), Vereeniging (Hatch and Corstorphine), are not situated on the outskirts of the assumed glaciated area. On the contrary, even at this stage of South African geological investigation, it is clear that these stratified deposits occur near the *central part* of the area of maximum development of the assumed glaciation and even relatively near to the emanation region of the presumed ice-cap. These occurrences, so natural to products of volcanic origin, constitute ever so many instances refuting the assumption of continental ice-capping or other glaciation and of the glacial origin of the Dwyka conglomerate. Thus stratigraphically as well as structurally the

FIG. 6.—The Blonkeng valley, with the Merapi volcano (Java) on background, showing banked condition of volcanic material deposited by successive mud-flows. The valley served and is still being used as a passage to the mud-flows in their downward course, the torrent cutting its trench again and again in the newly deposited material. After a photo by Kemmerling from (7*a*).

modes of occurrence of the Dwyka (Karroo) deposit are irreconcilable with the glacial theory of its origin (compare Plate IV).

So are (*a*) palaeontological and (*b*) petrographical evidence, as we shall see.

(*a*) In this supposed "glacial" deposit, fragments of *Cordaites* or *Psygmophyllum* were found. Consequently du Toit (22, p. 210) had to conclude that "The fact that a fragment of either a *Cordaites* or a *Psygmophyllum* frond was discovered in one of the masses

points to the quartzite's having most probably originated as an *interglacial sand*" (Matjesfontein, South-Western Cape Province). A. du Toit's observation consequently compels to admit one (or more) inter-glacial period(s) and *to account for its* (their) *origin as well*; which was never even attempted. And for reason. There is no discontinuity, no interruption [1] in the series which would support the assumption of one or more interglacial periods. In fact, du Toit's solution of the enigma, hardly satisfactory when one considers simply the abnormal thickness of the ice-covering, becomes totally unacceptable when one studies the stratigraphical position in which these plant remains have been found to occur and the palaeo-geographic relation between the supposed ice-cap and the said occurrences. Try as we may, it is impossible to separate stratigraphically or geographically such strata of the Dwyka-Ecca series as contain plant remains from those which are devoid of them; they occur pell-mell below, in, and above the Dwyka, all over the so-called "glaciated" area. "Even along the southern margin of the Karroo, the shales below and between the conglomerate beds do not differ from those above, and *the same types of plant remains occur throughout* (6, p. 199). *There is therefore neither a stratigraphical nor a palaeontological reason for their separation*" (my italics).

The very coal deposits at Viljoensdrift, Vereeniging, and the East Rand are *interbedded with the "glacial conglomerate"* (6, p. 214). "Fragments of trunks of *Sigillaria*, leaves and stems of *Glossopteris* play an important part in the composition of the coal itself" (12, p. 76). Moreover, these Vereeniging beds like the majority of the, other coal-deposits of the Transvaal, are, undubitably autochtone i.e. formed by the growth of vegetation in situ (23, p. 222) of the *Glossopteris Flora*, which, as we shall see, has also been established lately in undisputed Dwyka conglomerate or so-called "tillite". Since 1905 it was established already that: "The coal seams east of Springs are often overlaid by bands of breccia, quite indistinguishable from the underlying breccia; and the upper sandstones, at Benoni, are frequently crowded with boulders of varying size, all the result of glacial activity" (6, p. 212). (See also 12, p. 62, quoted below, and 23, p. 210 sub. (*c*).)

It might be objected, although there seems no real foundation for such assumption, that the Springs-breccia, like other similar ones, may be on secondary site. To remove all possible doubt and forestall any controversy on the subject, I may finally quote from T. N. Leslie's Presidential Address:—

(9) "In a local exposure on the banks of Zuikerbosch River, about three miles east of Vereeniging, in some stratified beds which appear to be of fluvial origin, I have long known the existence of the

[1] du Toit (21, p. 204) indicates two unconformities in the Dwyka series of the Central Transvaal region, one at its base and the other at its top, which apart from being problematic stand in no relation whatever to his suggested interglacial period(s).

long strap-shaped leaf of the *cordiates*, but only recently have I found undoubted evidence of plant fossils in the actual glacial conglomerate itself" (i.e. fairly well preserved impressions of *gangamopteris*).

All over the Karroo covered area of South Africa we find irrefutable evidence that before, during, and after the so-called "glacial" period plant life of a far more tropical than polar character was more or less abundantly developed, during the time which is now subdivided in Dwyka and Ecca. ((23) compare pp. 215 and 274 ff.)

du Toit's conclusion on this subject is psychologically very remarkable indeed (23, p. 214). Commenting the Dwyka fossils, he writes: "Though it would hardly be expected that the tillite should contain fossils, *Gangamopteris* has actually been found jammed in between the boulder-bed and the glaciated floor near Strydenburg, north of Britstown, while at Vereeniging well preserved fronds were discovered by Leslie in a shaly layer in similar position right against the Dolomite. These are important finds, since they show that *the Glossopteris Flora was already flourishing in South Africa, while glacial conditions held sway*" (the italics are mine). (Compare (22), p. 210.)

One is at a loss to understand how the fiction of a continental glaciation—of such exaggerated dimensions at that—could have originated, become generally accepted, and can still be maintained *à outrance*, against evidence which should have been damning even were it quite unsupported.

Yet besides the stratified condition of the deposit and palaeontological evidence already mentioned, there is its petrographical constitution over the entire area which is also irreconcilable with the glacial theory.

(*b*) In the Transvaal region especially we have it on Molengraaff's testimony (12, p. 62) that: "All the characteristics of the Ecca beds recur in the stratified portions of the Dwyka conglomerate, and from a petrographical point of view we might therefore speak of an interstratification of true Ecca beds with the Dwyka conglomerate."[1] The same may be said, as is demonstrated above, from a stratigraphical, a structural, and a palaeontological point of view of Natal, the Orange Free State, and the Cape Province, as Molengraaff's conclusion for the Transvaal holds good for the whole Karroo-covered area. Examining it further petrographically, we find that the Dwyka conglomerate is characterized throughout by the accumulation of blocks, boulders, pebbles, and smaller fragmentary material of various sizes, ranging from blocks of some hundred tons in weight to mere grains, imbedded in a fine-grained, *crystalline matrix*. Throughout, the material of the conglomerate—the coarse

[1] Although the present conventional subdivisions of Dwyka and Ecca do not exactly coincide with those of Molengraaff here referred to, his conclusion remains unassailable now as it was then.

and that of the matrix alike—is more or less angular, chippy, round edged, yet not spherical nor elliptic like river or beach-worn shingle. It consists of igneous rocks, such as Granite, Gneiss, Diabase, Porphyrite, Veinquartz, Felspar, etc., and Quartzites, locally strongly enriched by fragments of such rocks as happened to be in situ in the neighbourhood.

"Striking, nevertheless, is the uniformity of the material, so different from any ordinary conglomerate, and this throughout an unbroken thickness sometimes of many hundreds of feet," du Toit appropriately remarks. This a priori resemblance to other breccia of undeniable eruptive origin (23, p. 207; 25, p. 382) gradually changes to identity on closer examination of the constitution of

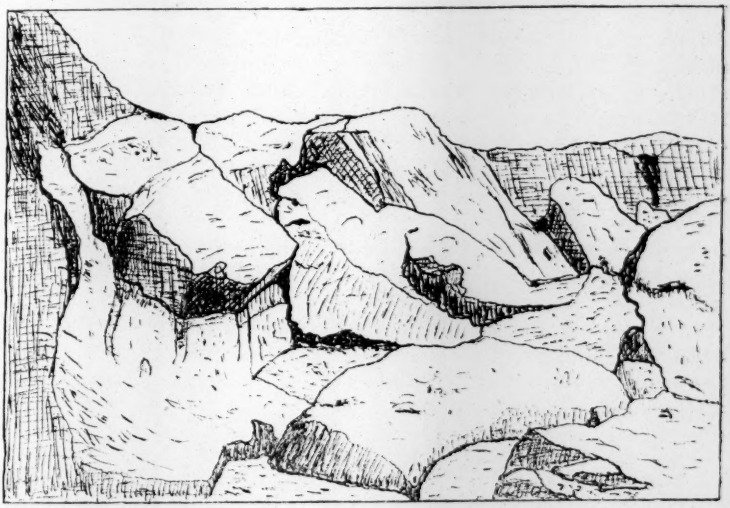


FIG. 7.—Deposit left by a "nuée ardente" in the Rivière Sèche (Martinique) after A. Lacroix, showing blunted, edge-rounded boulders and blocks imbedded in a crystalline matrix of volcanic ashes, of remarkably uniform composition over vast areas and through enormous thicknesses.

the conglomerate, which "both in microscopic characteristics and general appearance" is generally admitted to bear a remarkable resemblance to igneous rocks (4, p. 153; 23, p. 207).

Under the microscope its matrix proves to be crystalline, largely consisting of angular and semi-angular felspar (*very often quite fresh at that*) and quartz, embedding minute fragments of the same rocks which constitute the pebbles and boulders of the conglomerate. Such prima facie evidence, confirmed by microscopic investigations, of the nature of the deposit characterizing the entire Dwyka-covered area of South Africa, fully justifies Draper's exasperated exclamation (4, p. 154): "It is also strange that such experienced geologists

as the late Professor A. H. Green, Professor Seely, Dr. Gregory, and Dr. Hatch" (himself, Corstorphine until 1898, A. R. Sawyer, and others), "all of whom have examined this rock in situ should have misinterpreted the occurrence of the Dwyka." Like Bain, they were all convinced of its volcanic origin.

Molengraaff's further attempt to conciliate this apparent contradiction—this embarrassing crystalline and angular habitus of the *matrix* even of the conglomerate—with the pretended glacial origin of the Dwyka seems far from convincing. He attributes the former to a recrystallization brought about by mechanical (pressure) and chemical action. As to its angular habitus, the very constitution of such a *glacial mud*, which in this case would have been the product of intense grinding under excessive weight—an ice-cap of 4,000 to 5,000 feet thick—is in flagrant contradiction to the *pronounced angular* and *semi-angular* condition of the tillite's component particles (23. p. 208). Moreover, its degree of crystallinity is strikingly *uniform* all over the area. Such a habitus is primary, and therefore as natural to an accumulation of *volcanic* ashes and other loose volcanic ejecta as it is unnatural to *glacial muds*; whence it was contended that it is secondary, superimposed. Yet any conclusive support to such contention is still wanting, so that it leaves the impression of having been ingeniously formulated to get out of an embarrassing difficulty rather than of a well-founded argument. Incidentally, it may be observed that as the agents which would have caused such recrystallization (chemical action and pressure) must have been relatively extremely active in one place whilst nearly absent in another, in accordance with various conditions which prevailed locally, their effects should have been different locally and should vary say from a more or less completely developed crystallinity to a more or less amorphous state. The Dwyka matrix not showing such diversity of constitution, it must be admitted that its uniform crystallinity is a primary quality and consequently again irreconcilable with the assumption of a glacial origin. On the contrary, this feature so characteristic for the entire deposit—and the Ecca strata—wherever met with in this vast area, again very strongly points towards its being a product of volcanic origin.

The most obviously tempting foundation of the glacial origin theory, the cornerstone of it, is the occurrence of *striated blocks, boulders, pebbles,* etc., sometimes abundantly, in the Dwyka, and the *polished* and *grooved* condition of the variously constituted substratum of the conglomerate often observed in different parts of the Dwyka-covered area. It constitutes the crux of the problem.

"Not only is the great variety and size of the boulders remarkable, but a large proportion of them have scratched and striated surfaces. . . . When, furthermore, it is observed that beneath the boulder-bed the rock-floor is polished and finely striated, the conclusion is inevitable that only moving ice can explain all the phenomena and that the *boulder-bed is therefore a very ancient moraine* . . ." (23, p. 208).

The fascination of such occurrences is so powerful that their very appearance seems sufficient evidently to lead even very serious observers to the a priori, "inevitable," conclusion of an erstwhile glaciation as its origin, in direct opposition, as we have seen above, to stratigraphical, palaeontological, petrographical, climatological, and other considerations, however refutatory the nature of these considerations may be. (See also 19, p. 9.)

The contentions still to be seriously probed are, therefore :—

(*a*) Does the occurrence of scratched pebbles and boulders, striated, grooved, and polished bed rocks, *roches moutonnées*, even when their presence has been established at various places over a vast area, constitute a priori evidence of their having been originated by glacial action ?

(*b*) Do such phenomena so exclusively pertain to the glacial phenomenon that their occurrence justifies one conclusion only about their origin, even in spite of most serious direct and indirect refutatory evidence ?

FIG. 8.—"Roche moutonnée" with parallel striae protruding from Dwyka conglomerate after G. A. F. Molengraaff (12).

The reply to these questions must be an unreserved negative. There is still current a too ready tendency to ascribe to glacial action any occurrence of scratching and grooving, facetting and polishing wherever found on boulders and rocks in situ, irrespective of probable or improbable general or local considerations (19). In consequence the real nature and origin of these phenomena have not been studied seriously yet, although to-day we know them to be various (2, 7, 8, 14, 17, 24, 25). Such a tendency was natural in 1898, and Molengraaff's decision in favour of the glacial and against the volcanic theory of the origin of the Dwyka was well nigh inevitable, even against the strong phalanx of contradictory evidence, palaeontological, lithological, etc., detailed above. No other cause seemed plausible or conceivable at the time. Yet the whole question and its foundation have needed reconsideration ever since Branco (later—1901—in collaboration with Fraas) (2) [1] collected and published

[1] See e.g. pp. 139 et seq., recording the confirmation of the conclusions of the authors by Rothpletz, Léon, du Pasquier, J. Blaas, Stanislas Meunier, Gümbel, Penck, and others.

irrefutable proofs that all these phenomena, hitherto considered as products exclusively of glacial action, as *eo ipso* evidence of glacial activity, were produced in identical form by volcanic, torrential, and tectonic action. (See also 7, pp. 384–5.)

Since 1920 we even need not go outside of South Africa for confirmatory evidence on the subject.

P. A. Wagner describes such occurrence of striated boulders, of admittedly volcanic origin, from the Salt Pan crater situated north of Pretoria in the Bushveld Igneous Complex (Transvaal), from which description, being remarkable in more than one way, we will quote: (24, p. 53) "The breccia"—in a cutting through a ring-shaped encompassing ridge constituted of the said breccia—"has a maximum exposed thickness of about 26 feet. As already stated, it is made up exclusively of angular blocks of coarse red and pink biotite-hornblende granite (the local country rock). The boulders are irregularly piled up on top of one another, *the interstices between the larger ones being occupied by finer material.* They are clearly in exactly the position in which they fell after being violently expelled

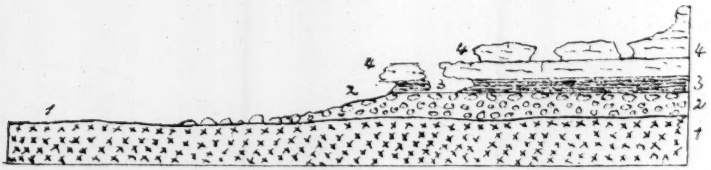


FIG. 9.—Section on right bank of Elandsriver (Transvaal) after E. T. Mellor showing stratified condition of Lower Karroo. (1) Red granite; (2) Dwyka conglomerate; (3) Shale and mudstone; (4) Coarse grit and sandstones. *Note.*—The striated rock underlying the Dwyka conglomerate—a Waterberg Sandstone—near by, is not shown on the section.

from the vent" (the Salt Pan crater). "*In places a rude stratification can be made out*, the breccia dipping at a low angle away from the Pan . . . *Some of the boulders are grooved and striated, probably as a result of mutual attrition*" (the italics and bracketed remarks are mine). In the ring-shaped encompassing ridge we find thus reproduced all the main features characteristic of the Dwyka deposit, viz. rudimentary stratification, predominance of local material, grooved and striated boulders, angular and sub-angular. It most probably constitutes a remnant of the caldera of the Salt Pan volcano, the pipe of which, in the earlier main eruptive period, may have been one of the emanation points of the Bushveld Igneous Complex phenomenon. It is further noteworthy that to the south-east of the occurrence with its grooved and striated boulders above described, on the very southern boundary of the Bushveld Igneous Complex, E. T. Mellor (10) found a typical Dwyka deposit, now well known in geological literature, covering grooved and striated Waterberg Sandstones.

Strangely enough, such reconsideration has not been accorded to the problem, which is the more astonishing because the Ries occurrence described by Branco and Fraas (2) above mentioned—essentially and even in many of its details identical with the South African—contrasts with the latter in one respect of great importance. Whilst in the nearly undisturbed, flat-lying Ries region the idea of volcanic activity having occurred at any time seemed fantastic, it is very evident and generally acknowledged that volcanism was very active all over South Africa in the periods at least before (Vredefort—Bushveld—etc.) and after (Middle and Upper Karroo) the formation of the Dwyka conglomerate [1] (5, 22).

With the acknowledgment that identical phenomena have been produced by glacial *and* by volcanic action, the last pillar pretending to support the theory of the glacial origin of the Dwyka is destroyed.

Recapitulating, we are led to the following inevitable conclusions:

That structural, stratigraphical, tectonical, palaeontological, and petrographical direct evidence is all either inconsistent with or not pertaining exclusively to the glacial assumption;

That where such evidence is not in contradiction with the said assumption—striation, etc., and local absence of pronounced stratification—the characteristics concerned pertain equally to glacial and to volcanic deposits;

That, on the other hand, all the peculiarities observed, taken singly as well as in their mutual relation, together with general geological considerations on the subject, are all perfectly consistent with the contention that the Dwyka is of volcanic origin;

And that consequently recognition of the real, i.e. volcanic, origin of the Dwyka, must be substituted for the current erroneous belief with its endless self-contradictions.

Having analysed the evidence fundamentally governing the problem and consequently established the real nature of the Dwyka deposit, it is necessary to determine the period and the site of the volcanic action concerned and to determine in how far the various well established characteristics of the deposit are consistent with the conclusion arrived at above.

A study of Central South African tectonical conditions shows that, generally speaking, no strata younger than the Pretoria series have been subjected to the main orogenetic folding of the Transvaal–Orange Free State–Northern Cape Province region.[2]

These series have been folded together with the underlying systems by the huge magmatic upheaval, eruptions and extrusions exemplified

[1] (5, p. 2.) Further investigations will probably show that the uplift, or depression, of the Heidelberg beds and later intrusive of the Kimberlites and melilite-olivine-basalt of Spiegel River are due indirectly to the same root cause—the great mountain building movements and uplifts of strata—which extended from Permian to late Mesozoic times and so entirely altered the configuration of the sub-continent.

[2] The correlation of the pre-Karroo (and later) formations that occur in the various parts of South Africa is yet problematic and doubtful.

in the occurrence of the Vredefort, Klerksdorp–Johannesburg, Bushveld and Barberton granites, their associated systems of dikes, sills, etc., and subsequent manifestations of gradually diminishing volcanic activity, in more recent times.

The orogenetic movements concerned must have occurred therefore in post-Pretorian age.

The folded complex, or the eruptive rock, as the case may be, is locally covered by the Waterberg—respectively by younger—systems generally in horizontal or more or less little disturbed positions.

This fact, taken together with the composition and structure of the Waterberg series, which, to a large extent, are characterized by sandstones and grits whose nature points to a sub-aerial rather than to a sub-aqueous deposit, makes it probable that these series are composed of the indurated products of the first loose ejecta (fragments of the original cover, ashes, lapilli, bombs, lava, etc.) of the huge volcanoes, of the Central South African main eruptive-orogenetic phase. (Bushveld–Vredefort.)

In the southern Cape Province the tectonical features are far more complicated, whilst a good topographical basis for accurate geological mapping is wanting there, as elsewhere in South Africa. In spite of the excellent work already rendered by the Geological Survey and others, it is therefore extremely difficult as yet to unravel the details of its tectonical structure with any large degree of accuracy.

We may take it as an established fact, however, that the Karroo System—conveniently subdivided in Dwyka, Ecca, Beaufort, and Stormberg Series—has been deposited without any considerable break from the base to its top, which for the fully developed system means from the basal Dwyka to the Stormberg Basaltic Lavas.

We also know that on the south and south-western side of the Karroo the basal Dwyka lies conformably on the Witteberg Series, together with which its strata have been tilted (Lainsburg and Wittebergen region), whilst in the north and north-west of the Cape Province there is a marked unconformity between the base of the Dwyka and the underlying rocks.

It is clear consequently that the beginning of the main eruptive phase in the latter area must have preceded that of the southern Karroo above indicated, thereby covering the Witteberg Series conformably with a thick layer of Dwyka deposits, the former being covered, at least locally, by fresh water basins. Subsequently volcanism or—to avoid equivocal interpretation of the word—magmacratism became active in the southern Karroo, raising and tilting the older complex and the Witteberg strata with their overlying deposits.

Self-consuming, gradually diminishing magmacratic activity continued during the entire Karroo period, maybe even beyond, successively manifesting itself at various times and places over the whole South African sub-continent, yet most intensively in the

Karroo-covered area and of that of the region of the north-eastern Cape Province, Basutoland, Orange Free State, Western Natal. It caused the ejected loose material and occasional huge lava-flows to be banked up higher and higher and riddled the enormous accumulations of products of former activity by successive intrusions of dykes and sills and piercing volcanic pipes.

Tremendous downpours accompanied and followed these volcanic outbursts, causing lakes and pools, rivers and torrents, the latter cutting deep into the loose material. These downpours, moreover, cause the ejecta accumulated on the mountain slopes, ashes, lapilli,

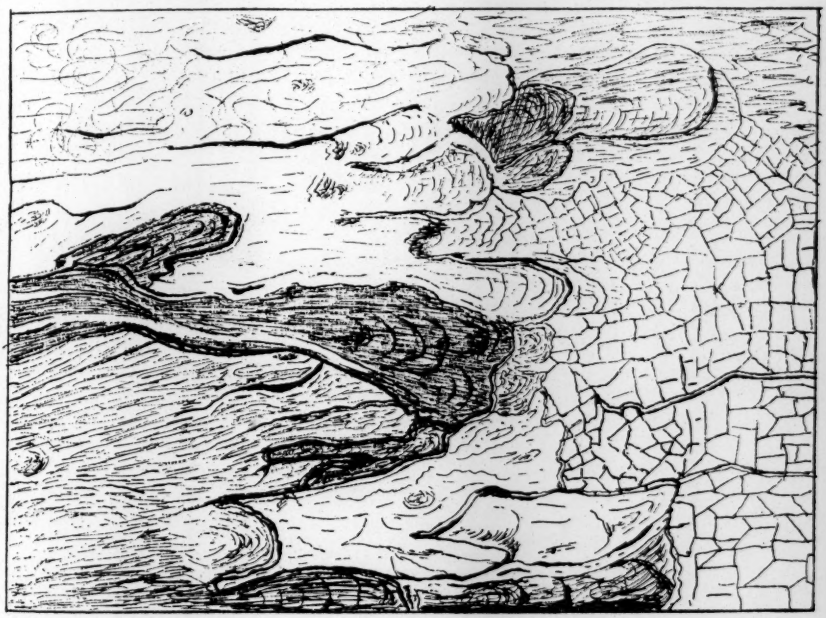


FIG. 10.—Copy of an aeroplane photo by Feenstra (21, p. 104) giving an idea of the extension and superposition of successive mud-flows descended from the Guntur volcano (Java) into the plains at its foot, 20 to 30 kilometres away from its top.

bombs, and blocks of fantastical dimensions occasionally, to be transported by way of huge mud-flows 20 to 30 and more kilometres away into the plains, depositing the debris in the form of powerful banks, the constituting material of which being arranged in chaotic or more or less well stratified order (7*a*, 19, 20, 21, 25, pp. 397, 399 ff.). At the very base, on the contact with the country rock, we may expect these deposits of a uniform constitution throughout, to be enriched by fragments of the country rock which was pierced and scattered by the first volcanic outbreak, whilst higher up these

will be extremely scarce or entirely wanting. The loose ejecta deposited on primary site, would be characterized by the *chippy sub-angular or edge-rounded* condition of its material, whilst the ejecta transported by torrents and/or mudflows would be typified by the sub-angular and more or less rounded form, and their larger contingent of scratched and grooved stones and boulders. (See above and 13, p. 106 ; 2, 25.)

It should be noted also that Lacroix and others (8, 25, pp. 397–8) observed in various regions that these mudflows often resemble lateral moraines in a most confusing manner, and that they may become indurated by diagenetic processes so as to affect the habitus of sandstones and grits—so familiar e.g. in the Karroo (and Waterberg) Series—or even that of lava-flows in a way so confusing as to deceive even experienced and most conscientious observers (R. D. M. Verbeek, 21).

Thus we may appreciate the importance of Draper's observation (4, p. 153) : " I found in several instances what I then considered to be gradations of the Dwyka into igneous rock and vice versa " (see also Fig. 8).

The intense interfriction of the material of these mud-flows (lahars) [1] and their mechanical action on the walls and bedding of the torrents would cause the constituent rock fragments to be blunted, striated, or polished, and would produce " glacial " marks also on the country rock of their banks and beddings. See Pl. IV, Fig. 2 (2, p. 139 et seq., 25).

Apart from this cause, much of the grooving and polishing found on fragments and boulders of igneous rocks will be due, probably, to other causes than that of scratching *stricti sensu*. They may be e.g. the remnants of rents and cracks in the crust of volcanic bombs and other ejecta of various sizes and shapes, which penetrated comparatively deep into the body of the object concerned, and were " prepared out " subsequently. Such crust, falling a ready prey, as is well known, to decomposition, is subject to rapid removal as a result of intense friction, often under heavy pressure, in the body of a mud-flow in motion. The more solid, pseudo-grooved body of the " boulder " would thus lose its weathered envelope and become polished, its polished condition rendering it still more subject to scratching and at the same time more resistant to decomposing influences.

As to the parallel grooving and polishing observed on country rock in situ and lavas, it is most likely that they are of varying origin, too. Besides acknowledging, for several instances, a tectonic cause—faulting, over-thrusting, etc.—these phenomena may be conceived to represent in some instances the solidified marks impressed by its solid crust on a viscous body—e.g. a lava-flow or subjacent rock mollified by the excessive heat of its cover. H. Reck (14) describes

[1] Lahar is the name for mud-flows commonly used in Java (19).

parallel grooving on the surface of lava-flows brought about in this way and indicating the direction of flow of the viscous, igneous mass. It seems appropriate to note here that such solid crust, the scoria, eventually though not necessarily in conjunction with volcanic ashes accumulated in the interstices of the scoria, may be transformed by diagenetic processes (E. Haug) such as weathering, recrystallization, etc., into " conglomerates " exactly similar to the Dwyka, and even deceptively resembling conglomerates due to fluviatile and marine action. (See Draper's remark, p. 120.)

Wherever a sharp contact occurred between the fluid body of a moving lava flow and its crust, a polished or grooved surface might be imposed on the highly viscous material of the former which, after a lapse of time, would then support a " conglomerate ", the pseudocause of such grooving and polishing of the eruptive rock. Where the transition between the crust and the body of a lava flow was more

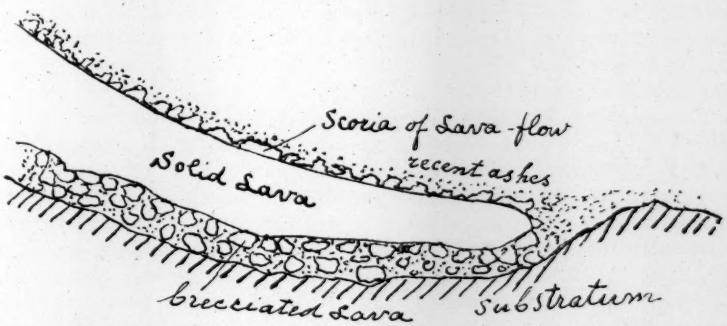


FIG. 11.—Ideal section of a lava-flow, covered and covering volcanic ashes, illustrating a possible mode of formation, by subsequent diagenetic processes, of upper and lower conglomerates, which may be gradually transitory into eruptive rock below or above it.

gradual, their transformation by diagenetic processes might result in a gradual transition of a " conglomerate " into an underlying, more or less easily recognizable igneous rock. These are but suggestions, the validity of which has to be studied on the spot.

It is clear that the all-important palaeontological evidence, which constitutes such a hopelessly inextricable enigma, when considered from the glacial point of view, becomes perfectly intelligible when admitting the Dwyka's volcanic origin In fact, we are actually witnessing that in all but arctic or semi-arctic regions perhaps, yet most markedly in tropical and semi-tropical areas, vegetation is intensively stimulated by conditions prevailing in regions where volcanic activity is still going on. The atmospheric precipitation is intensified, the temperature of the soil and the air above it as well as their contents of carbonic acid and other stimulating matter, are augmented while the loose volcanic ejecta and heavy mud-flows

furnish soils of extraordinary fertility. All these factors combine to cause luxuriant forests with heavy undergrowth to spring up and develop, vast swamps to become rapidly filled up and converted into extensive and thick deposits of forest-covered peats (which may acquire thicknesses of 8 metres and more even [1]) and transported vegetable material to be accumulated at propitious places by the action of torrents and rivers. Changing their courses occasionally the latter will cut across such forests, peat-swamps, and bogs, replacing by gritty material the vegetable matter they removed when cutting their new channels (23, p. 222).

Finally, subsequent volcanic outbursts—or any other cause, as the case may be—cause the coal-producing vegetable material to be buried or re-buried again and again and fossilized more or less completely, turning it into coal, lignite, peat, etc., etc., in quantities which may be exploitable or reduced to mere indications.

We see all these processes being accomplished under our very eyes in various parts of our globe, and we are able to follow the successive stages of their development which result in identical phenomena as we find to have been preserved in the Dwyka, Ecca, and higher series of the Karroo system.

The occurrence of carboniferous plant-remains so abundant in the Dwyka-Ecca (Lower Karroo) series thus becomes quite natural, and to account for the Dwyka's origin we are now exempted from having to resort to fantastical assumptions—such as of continental displacements of over 70 degrees latitude in South–North direction—in order to "explain" the origin of an assumed glaciation. It should be emphasized, moreover, that such assumptions, even supposing that their adoption could furnish a reasonable basis for explaining the occurrence of the presumed glaciation, demand to ignore, for fear of conviction—as is conveniently done—identical explicative obligations with regard to the occurrence of one or more interglacial periods, the problem of which is yet inseparably attached to the main presumption by the testimony of palaeontological evidence.

I would also emphasize the undeniable fact that climatic and atmospheric conditions required at the time for the production and luxurious development of a vegetation as that which evidently reigned in Dwyka-Ecca times need not have been so very different from those actually prevailing on a South African continent situated in the same geographical position as it occupies now, and that the intense volcanic activity of the period against its inactivity now, may amply account for the contrast between conditions of forestrial development which evidently reigned at the time and those which are actually prevailing.

Now that we have demonstrated that the current conception of the

[1] Deposits of 30 metres thickness of peat-coal (braunkohl) are known from South Sumatra (15).

origin of the Dwyka is erroneous, and shown why the theory of its volcanic origin should be accepted instead, it seems appropriate to substantiate a remark recently made (17 ; 18, p. 132) about certain central Alpine deposits to which a glacial origin, though a far more recent one, is currently attributed also.

It is clear from the above that the fact has to be taken into consideration more and more that certain deposits of volcanic origin may be quite indistinguishable in all their details from presumed or proved glacial deposits. This fact has been admitted, yet taken into account too little, even in the case of deposits occupying their original, primary site, such as ordinary primary accumulations of ejected volcanic bombs, lapilli, and ashes, and those caused by *nuées ardentes*, which latter deposit the ejected material in one predisposed elongated direction, as well as in the case of such material occupying a secondary site to which it has been transported as mud-flows after its original deposition. Both types may present features identical with those which are characteristic of glacial deposits.

Formerly the appearance of even an occasional scratched and polished rock surface in any deposit justified to stamp the origin of the deposit *eo ipso* as indubitably glacial, and such occurrence was considered an ample justification for a philosophy on glacial periods, their extent, duration, and origin. (South Africa, India, Gondwana, etc.)

The results of such action have been detrimental to South African geology in particular as well as to geology in general.

The real facts at present available are as much in perfect harmony with the contention of the volcanic origin of the Dwyka and younger Karroo deposits, as they are refutatory to the glacial assumption.

It is to the able staff of the Geological Survey of the Union of South Africa more than to anyone else, to probe the problem further fundamentally and in all its details, in a spirit of perfect objectivity and free of any preconceived ideas or opportunistic considerations, the only question which really matters being, not *who* is right, but *which* is right.

The cradle of these erroneous notions[1] at present current in geological science, lies in the region of the Swiss Central Alps, where the absence of tertiary and more recent volcanism was considered an incontrovertible fact. Hence the attribution of a glacial origin

[1] Its most eminent apostle in modern times is A. Penck, who in his zeal did not shrink from heaping assumption upon assumption and who thus arrived at various most daring conclusions. Unfortunately these became currently accepted dogma in geological circles. Built on admittedly trumpery evidence of scratched stones, the theory and Penck's deductions are yet vainly in search of plausible explanations for the origin of such a fall in temperature, repeated at intervals at that, which could have caused in the regions concerned conditions of super-glaciation over expanses of continental order. Here again exaggeration has led science on a false track to retrieve which will demand a long time and much energy.

to all such occurrences of erratic material there and its extrapolation elsewhere.

Since, however, it could be established (17, 18) that volcanism has been active in the Central Zone of the Alps in Oligocene and more recent times, the acknowledged and so obvious identity in all but their origin of products of volcanic and glacial origin (real or presumed), demand a serious revision of the foundations on which the, in parts, phantastical structure of our glacial theory and its deductions have been erected.

LIST OF AUTHORS QUOTED.

(1) A. G. Bain, "On the Geology of South Africa": *Trans. Geol. Soc. Lond.*, vol. vii, 1856, pp. 175–92.

(2) W. Branco und E. Fraas, "Das vulkanische Ries bei Nördlingen": *Abh. Kön. Preuss. Ak. Wiss.*, i, 1901, Berlin, pp. 1–160.

(3) D. Draper, "The Dwyka Conglomerate": *Trans. Geol. Soc. S. Afr.*, vol. i, No. 1, 1896, pp. 90–103 and 104–9.

(4) —— "Notes on Dr. Molengraaff's Paper": *Trans. Geol. Soc. S. Afr.*, vol. iv, 1898, pt. vii, pp. 153–6.

(5) S. Harger, "The age of the South African Kimberlites and their occurrence in Cretaceous Beds": *Trans. Geol. Soc. S. Afr.*, vol. xxiv, 1921, pp. 1–10.

(6) F. H. Hatch and G. S. Corstorphine, *The Geology of South Africa*, London, 1905.

(7) E. Haug, *Traité de Géologie*, i, Paris, 1907.

(7*a*) G. L. L. Kemmerling, *De hernieuwde werking van den vulkaan G. Merapi, Vulk. Med.*, No. 3, 1921, Dienst v. h. Mynw. Weltevreden.

(8) A. Lacroix, *La Montagne Pelée et ses Éruptions*, Paris, 1904.

(9) T. N. Leslie, "Presidential Address": *Min. Proc. Geol. Soc. S. Afr.*, 1921, pp. xix–xxi. See p. xxiii.

(10) E. T. Mellor, "Outliers of the Karroo-System, etc.": *Trans. Geol. Soc. S. Afr.*, vol. vii, 1904, pp. 133–5.

(11) —— "On Some Glaciated Land Surfaces": loc. cit., pp. 18–26.

(12) G. A. F. Molengraaff, *The Geology of the Transvaal*, Esson & Perkins, Johannesburg, 1904.

(13) —— "The Glacial Origin of the Dwyka Conglomerate": *Trans. Geol. Soc.*, vol. iv, pt. v, 1898, pp. 103 ff.

(14) H. Reck, "Isländische Masseneruptionen": *Geol. Paleont. Abh. v. E. Koken, Jena*, 1910, N.F., Bd. ix, Hft. 2, pp. 48–9.

(15) L. M. R. Rutten, *Voordrachten over de Geologie van Nederlandsch Oost-Indië Groningen*, J. B. Wolters, 1927.

(16) C. G. S. Sandberg, "On the probable Origin of the Members of the Bushveld Igneous Complex": Geol. Mag., Vol. LXIII, No. 743, 1926, pp. 210–19.

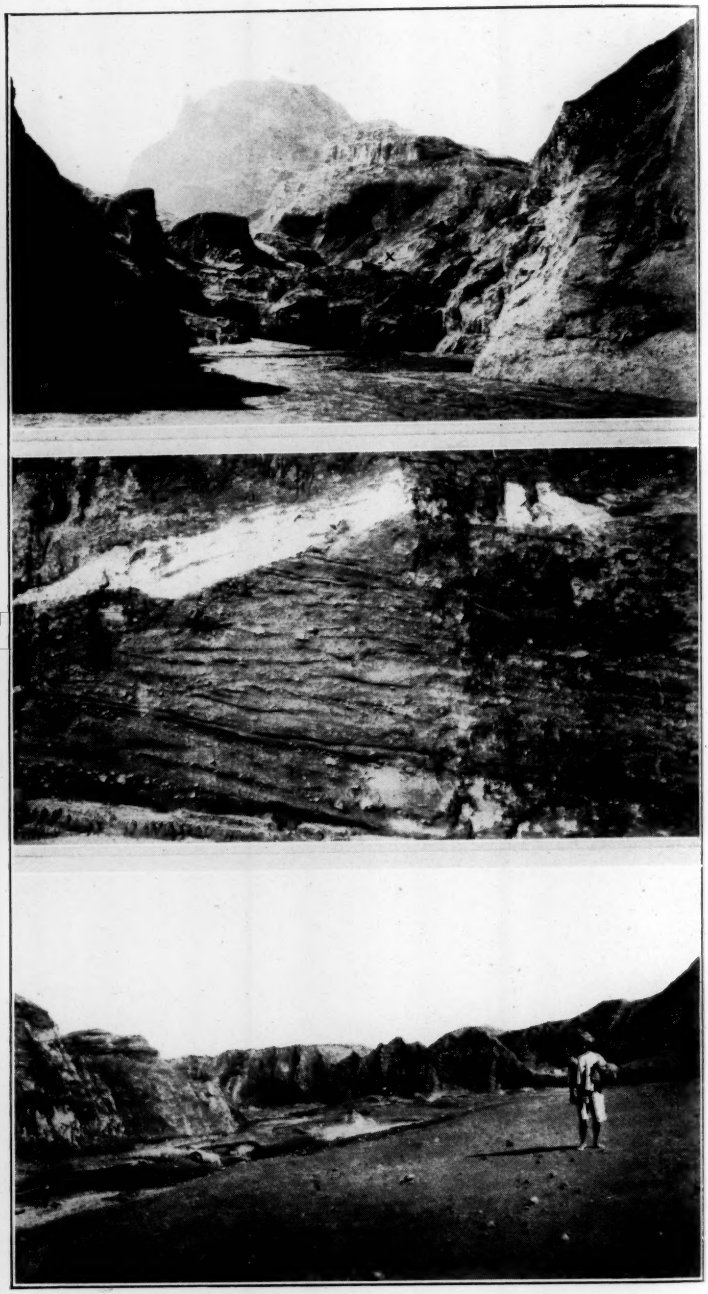
(17) —— "Recent Volcanic Eruptions in Central Alpine, so-called 'Hercynian' Zone": Geol. Mag., Vol. LXIII, No. 748, 1926, pp. 469–78.

(18) —— "Einiges über die Zentral-sog. "Herzynischen" Massive, u.s.w.": *Zeitschr. der Deutsch. Geol. Ges.*, Bd. 79, 1927, Abh. 1 u. 2, pp. 122–35.

(19) G. Stutzer, "Ueber einige Ergebnisse meiner geologischen Reisen in Kolumbien": *Zeitschr. d. Deutsch. Geol. Ges., Mon. Ber.*, 1–2, Bd. 79, 1927, pp. 5–13.

(20) N. J. M. Taverne, "De Aardbevingen van Wonosobo, etc.": *Vulk. Med.*, No. 8, Dienst v.h. Mynw. in N.I. Weltevreden, 1924.

(21) —— "Vulkaanstudieën op Java": *Vulk. Med.*, No. 7, Dienst v.d. Mynb., The Hague, 1926. (Volcanological Studies in Java.)



1

2

3

VIEWS OF BADAK MUD-FLOW, JAVA.

(Descriptions on p. 139.)

To face p. 159.]

(22) A. L. DU TOIT, " The Carboniferous Glaciation of South Africa " : *Trans. Geol. Soc. S. Afr.*, vol. xxiii, 1921, pp. 188–227, with map.
(23) —— *The Geology of South Africa*, Oliver and Boyd, London, 1926.
(24) P. A. WAGNER, " Note on the Volcanic Origin of the Salt Pan, etc. (Transvaal)" : *Trans. Geol. Soc. S. Afr.*, vol. xxiii, 1921, pp. 53–8.
(25) F. v. WOLFF, *Der Vulkanismus*, Stuttgart, 1914.
(26) W. F. F. OPPENOORTH EN J. ZWIERZYCKI, *Landschapvormen in Noord-Sumatra. Jaarb. v.h. Mynwezen. Verh.*, 1917, Batavia, 1918, p. 2.

EXPLANATION OF PLATE IV.

FIG. 1.—Ravine of the Badak mud-flow (lahar) on the western flank of G. Këloet (pron. Kelut) showing alternations of stratified and unstratified deposits of successive mud-flows and intercalation of " dwyka " conglomerate (above ×). Photo 14, Dr. Mulder from G. L. L. Kemmerling, *Vulk. Med.*, No. 2, 1921.

FIG. 2.—Walls of the Badak torrent showing system of parallel striae and grooves, caused by the action of descending mud-flows (Lahars). (Photo 15, loc. cit.)

FIG. 3.—Curve in the Badak mud-flow (lahar) showing " conglomerate " formation at its surface. (Photo 16, loc. cit.)

REVIEWS

A GEOLOGICAL COMPARISON OF SOUTH AMERICA WITH SOUTH AFRICA. By A. L. DU TOIT, with a palaeontological contribution by F. R. COWPER REED. 157 pp., with 16 plates, a coloured map and 7 text-figs. Published by the Carnegie Institution of Washington, 1927.

WHATEVER views geologists may hold as to the *a priori* probability of the Wegener-Taylor theory of continental drift it is safe to say that no one will be found to deny that this memoir merits the most careful consideration, since it presents in a masterly manner a vast mass of facts of observation, going, it may be said, far beyond the possibilities of mere coincidence, as to the geological similarities that exist between South Africa and South America. It is hardly possible to imagine any one better fitted then Dr. du Toit to undertake the comparison. Besides a most minute acquaintance with the details of South African geology, as set forth in his great book recently reviewed in these columns, he has also a working knowledge of the Australian equivalents of the rocks concerned.

From the facts here set forth it is quite clear that the similarity between South Africa and South America is extraordinary, even down to minute details, lithological, as well as palaeontological, and it is very important to note that this similarity is by no means confined to the rocks of the Karroo system and its equivalents, the so-called Permo-Carboniferous, which is what most people have in mind when they envisage the problem. The resemblances are equally striking in the Siluro-Devonian-Lower Carboniferous sequence (Table Mountain Sandstone, Bokkeveld and Witteberg series of the Cape) which are faithfully reproduced in South America.

The igneous rocks and the distribution of the Cretaceous and Tertiary are also very similar on both sides of the Atlantic, and there are the same striking resemblances even in the details of the high-level gravel terraces of both regions, not to mention the character of the scenery in many places.

Dr. du Toit makes a very good point when he shows that the differences of facies in a given formation are often greater within the limits of one or other of the continents than they are between the corresponding beds on the two sides of the ocean. Furthermore, when the maps of Africa and South America are slewed round and brought into juxtaposition, so that Brazil fits into the Gulf of Guinea in the well-known way postulated by Wegener, the trend-lines of the folded mountain chains correspond in a most remarkable manner. The Gondwanides of Keidel in Argentina thus become the direct continuation of the southern fold-ranges of the Cape (Langebergen, etc.) and the Brasilides of Brazil are found to be parallel to the chains that run down the western coast of Africa from just north of the mouth of the Orange River and form a syntaxis with the east-west ranges near Ceres and Worcester. It is to be noted that Dr. du Toit does not bring the two continents into actual contact, but postulates a gap of from 400 to 800 kilometres between them, the Falkland Islands being brought into this space directly in the line of the Cape Ranges and Gondwanides, with which their structure agrees.

However, as is always the case in a review, a few facts, however salient, extracted more or less at random, must necessarily fail to give a fair summary of an argument mainly dependent on a mass of detail. The final sections, setting forth the author's conclusions, are by no means dogmatic, but show a commendable restraint and impartiality of judgment, and are for this reason all the more convincing in favour of the hypothesis of continental disruption. As he takes care to point out, it is highly desirable that some competent authority should now undertake a similar comparison with the other areas where the Gondwana type is found.

The palaeontological appendix by Dr. Cowper Reed gives careful descriptions of a collection of fossilsmade by Dr. du Toit from Barreal, San Juan, Argentina, with a list of names only of some Triassic fossils from Rio Claro, Paraná, Brazil. The upshot of the study of the first group, put briefly, is to render it highly probable that the principal tillite of South America occurs towards the base of the Upper Carboniferous, as in the Salt Range of India ; thus giving a more or less exact date for the Dwyka conglomerate. The twelve plates devoted to South American rock-exposures are very good, especially plate i, which is one of the most striking pictures of rock-folds that the reviewer has ever seen. It is certainly very like some of the exposures in the Hex River Pass, Cape Colony, where the rocks are probably of the same age, both being involved in the Gondwanide folding.

R. H. Rastall.

THE ANTIQUITY OF MAN IN EAST ANGLIA. By J. REID MOIR. pp. xiv + 172, with 25 plates and 74 text-figures. Cambridge: At the University Press, 1927. Price 15*s*.

GEOLOGISTS and archaeologists alike will welcome this work, which, while dealing with general problems of prehistoric archaeology, gives special prominence to the author's own important discoveries in East Anglia. The various artifacts, from pre-Chellean to those of the Bronze Age, are dealt with. The author candidly states that the former are not accepted by everyone, but during the last few years the sceptics have diminished in number and many prominent geologists and archaeologists now believe in their authenticity.

The author's discoveries of implements in the Cromer Forest Series and in the mid-glacial sands of the Ipswich district naturally claim much attention. One criticism we would offer. In common with many archaeologists the author speaks of the dates of certain stages of human culture with too certain a note. The data on which such estimates are made are uncertain and the figures should be quoted with reserve. Similarly the *tentative* nature of the correlation of the glacial stages of the Danube with the deposits of East Anglia (p. 56) should be emphasized. It would have been easier for the general reader if the stratigraphical tables in the text had been given in their natural (instead of inverted) order so as to correspond with the order in the sections figured. The book is largely occupied with the author's own researches, and we are grateful for this excellent summary of his work; for he is not only thoroughly versed in the human relics of the various cultural periods, but has also a full and wide knowledge of the newer strata of East Anglia. We strongly recommend this book to all who are interested in the subject. Many will disagree with some statements, but all will read the work with advantage.

THE GEOLOGY OF THE COUNTRY AROUND VREDEFORT: AN EXPLANATION OF THE GEOLOGICAL MAP. By L. T. NELS. pp. 130, with 15 plates, and 8 text-figures. Geological Survey of the Union of South Africa. Pretoria, 1927. Price 10*s*. 6*d*. (including map).

THE peculiar structure of the "Vredefort Mountain Land" attracted attention many years ago, and since the publication of the great monograph by Hall and Molengraaff it has become so well known as to need no further description here. The map now published, on the special scale of 1 mile to the inch, and apparently not numbered, is a very striking production and a beautiful specimen of geological cartography. The accompanying well-illustrated memoir is naturally also of great interest and importance, and is worthy of very careful study.

R. H. R.

HANDBUCH DER PALÄOBOTANIK. Band I: THALLOPHYTA, BRYOPHYTA, PTERIDOPHYTA. By R. OLDENBOURG. 724 pages, 817 figures. München and Berlin, 1927. 48 marks bound.

PROFESSOR HIRMER'S first instalment of a comprehensive Handbook of Palaeobotany, to be completed in two volumes, deals with the lower classes of plants, Algae, Fungi, Bryophyta, and Pteridophyta; the second volume will include an account of seed-bearing plants; also chapters on the various floras and on other topics of general interest. Dr. Julius Pia, of Vienna, the recognized authority on certain groups of fossil calcareous Algae, is responsible for the introductory chapter on the preservation of plants as fossils and for the chapters on fossil Algae and Fungi. Dr. Troll contributes a section on Bryophyta. Notable features of the book are the well-chosen illustrations and the bibliographies. The present volume will be more useful to botanists than to geologists; it is mainly concerned with descriptions of genera and includes summaries of morphological characters which appeal more particularly to academic botanists. Geologists, on the other hand, will welcome a book of reference in which they can find clear descriptions and lists of species from different horizons. The citation of specific names alone, without reference to the distinguishing characters or unless the reader is referred to original sources, is not very helpful. It is perhaps too much to expect that a handbook of palaeobotany should include short accounts of the larger groups of the vegetable kingdom designed for non-botanical readers, but it would make descriptions of extinct genera more intelligible if some less technical comparisons were made of fossil with recent types. Dr. Pia in his chapter on Algae passes lightly over the difficulties presented by *Cryptozoon* and other problematical structures from the older rocks; he admits their small value as evidence of the occurrence of undoubted Algae, but he does not go so far as to suggest an inorganic origin. Geologists who depend upon palaeobotanists for expert information should be warned that many of the supposed examples of fossil Algae are valueless as botanical records. No reference is made under the genus *Epiphyton*, one of the older Palaeozoic Algae, to a Cambrian species described by Professor Gordon in 1920. A figure of *Parka*, a Lower Devonian plant of uncertain position, is borrowed from the excellent account of the genus by Don and Hickling in 1917, but the title of their paper is omitted from the bibliography. The account of *Solenopora* and some other multicellular calcareous Algae does not give an adequate idea of the importance of these plants as rock-builders in the Carboniferous and other Palaeozoic seas. No mention is made of a paper by A. Brown on *Solenopora*, published in the GEOLOGICAL MAGAZINE in 1894.

There is a good summary of our knowledge of the Middle Devonian flora based mainly on the petrified material from Rhynie and Elberfeld. Professor Hirmer has also succeeded in giving a clear account of the various genera of ferns, most of them from Lower

Carboniferous rocks of Burntisland and elsewhere, included in the Coenopterideae, a group of comparatively small plants differing both in habit and in many structural features from the more typical members of the group which are characteristic of later periods. It is always a pleasure to find some new restorations of *Lepidodendron* and other Carboniferous genera, and most of Dr. Hirmer's drawings have the merit rare in reconstructions of looking like plants that actually existed. The story of the Osmundaceae, one of the most complete of all fern genealogies, is well told. On the other hand, the treatment of some of the later families of ferns is hardly full enough to bring out the importance of palaeobotanical data to the student of evolution and geographical distribution. The common Australian plant *Leptophloeum* (*Lepidodendron*) *australe* is said to be from Palaeozoic rocks in Queensland ; this species, which is widely spread in Upper Devonian and in Carboniferous rocks in New South Wales and elsewhere, deserves more accurate treatment.

The more we learn of the Palaeozoic floras the more fascinating become the problems which are suggested by the word evolution: the oldest known terrestrial plants from the older Devonian strata, with a few fragments of Silurian age, exhibit certain features which are undoubtedly primitive ; but in the general plan of their anatomy they differ but little from species which still exist. The Upper Devonian floras with the widely spread *Archaeopteris*, which may or may not be a true fern, as a characteristic genus, give the impression of a phase in evolution remarkable for the high stage already reached in the differentiation and complexity of the plant-body. The great diversity in the vegetation of the Carboniferous forests and the morphological characters of vegetative and reproductive organs, far in advance of the organization of the modern representatives of the Palaeozoic families, illustrate both an extraordinary persistence of certain types through the ages and the necessity of recognizing that in the course of geological history there have been several culminating points in evolution from which from time to time development has not been progressive but retrogressive. Another striking fact which emerges from a review of the plant records is the marked difference between the later Palaeozoic floras and those which flourished in the earlier periods of the Mesozoic era. Continuity there must have been, but while there are a few links demonstrating continuity the gaps on the whole are the more obvious features.

Professor Hirmer has undertaken a very difficult piece of work, the compilation of an authoritative summary of a mass of widely scattered literature and a general review of the comparative morphology of the numerous extinct types ; he has succeeded in producing a valuable book of reference, but palaeobotanists will detect many inaccuracies in matters of detail.

A. C. S.